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SOIL SCIENCE

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SOIL · CHEMISTRY · AND · SOIL · BIOLOGY

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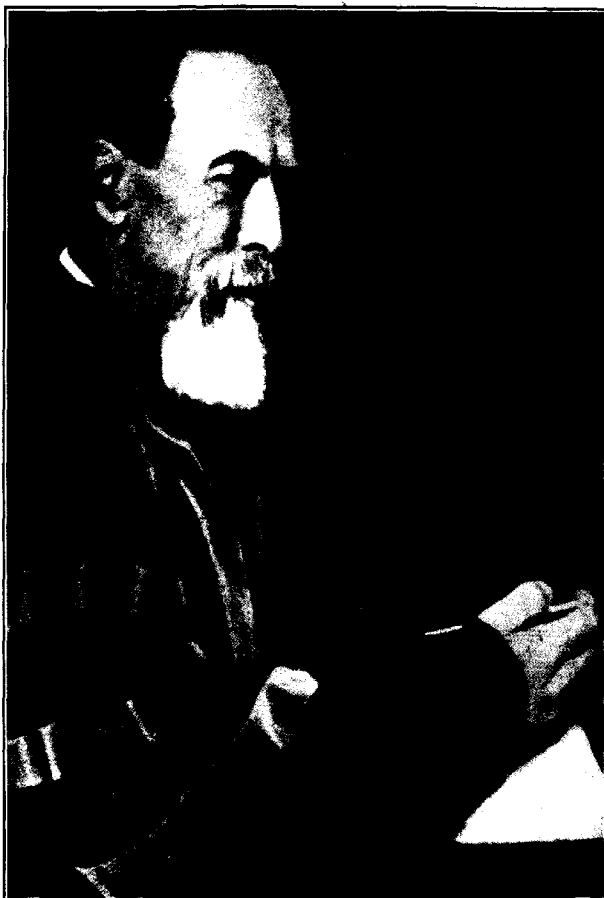
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ERRATA

- Page 17, line 8 from bottom, "nitrate" should read "nitrate."
- Page 48, 3rd page following, legend opposite Plate II, last line, "as" should read "at."
- Page 94, reference (10), title of article should read "Untersuchungen über das Verhalten des Ammoniakstickstoff in gekalkten und ungekalkten Boden."
- Pages 104, 108, 109-128, "Czapeck" and "Czapeck's" should read "Czapek" and "Czapek's," respectively.
- Page 110, line 17 from bottom, "*violaceus*" should read "*violaceus-ruber*."
- Page 125, line 11, omit "33."
- Page 129, line 21, "*albotratus*" should read "*alboatrus*."
- Page 131, Table V, "*violaceons-ruber*" should read "*violaceus-ruber*," and "*violaceons-Caeseri*" should read "*violaceus-Caeseri*."
- Page 134, 3rd page following, legend opposite Plate II, "*Act. albotratus*" should read "*Act. alboatrus*."
- Page 151, reference (9) should read "Koch, G. P. 1915. Activity of soil protozoa. *In Jour. Agr. Research*, v. 5, no. 11, p. 477-488."
- Page 180, line 14, "*bacillus fluoresens liquifi*" should read "*Bacillus fluorescens liquefaciens*."
- Page 182, line 14, "1 per cent" should read "0.03645 per cent."
- Page 188, line 4, "*bacillus fluorescens liqui*" should read "*Bacillus fluorescens liquefaciens*."
- Page 232, line 1, "Table XXXIV" should read "Table XXXIV."
- Page 274, reference (7), "Lyon, T. A." should read "Lyon, T. L.," and references (11) and (12), "Russell, E. H." should read "Russell, E. J."
- Page 325, Table VII, "January 17—February 20" should read "January 17—January 20." Also, insert "November 24—January 7" under line reading "Group B.—Formation of Nitrates."
- Page 386, legend of figure 2, "or" should read "of."
- Page 392, Table VI, heading of 1st column under "Dried Blood Series" should read "Incr. 1 c.c. over 0.2 c.c.", of 2nd column, "Incr. 5 c.c. over 1.0 c.c.", and heading of 1st column under "Cottonseed Meal Series" should read "Incr. 1 c.c. over 0.2 c.c."
- Pages 381-403, "The Inoculation and Incubation of Soil Fungi," by N. Kopeloff. Throughout this article, "*Zygorrhynchus*" should read "*Zygorhynchus*" (preferable form).

Dedicated to the Memory
of
Eugene Woldemar Hilgard, Ph.D., LL.D.
Zweibrücken, Bavaria, January 5, 1833
Berkeley, California, January 8, 1916



EUGENE WOLDEMAR HILGARD, Ph.D., LL.D., Late Director Emeritus of the Agricultural Experiment Station of California, and Professor Emeritus of Agriculture of the University of California.

EUGENE WOLDEMAR HILGARD

Zweibrücken, Bavaria, Jan. 5, 1833—Berkeley, California, Jan. 8, 1916

Having been granted the vision and the strength to achieve, Doctor Hilgard labored humbly and gratefully to the very end, in his chosen field of science. Born at Zweibrücken, Bavaria, in 1833, he studied at Zürich, Freiberg and Heidelberg and as a young man came to the United States for a long term of faithful and distinguished service. In 1855 he was appointed chemist of the Smithsonian Institute, but resigned in the following year to accept service with the State of Mississippi. He remained there until 1873 in the capacity successively, of assistant state geologist, state geologist and professor of chemistry. He then accepted an appointment as professor of geology and natural history at the University of Michigan. Ill health compelled him to resign in 1875 and to seek a milder climate which he found in California. There he studied, taught; and inspired many men for more than forty years. In his capacity as professor of agriculture and director of the agricultural experiment station he helped to build up the agriculture of a great commonwealth; but even more than that, he made important contributions to soil physics and soil chemistry and aided thus in the building of the foundations of the science of soils.

Not possessed of a rugged physique he was nevertheless a tireless worker and always eager to help. His responsibilities at the university did not deter him from important service elsewhere. As special agent of the Tenth Census, as one of the officials of the Northern Transcontinental Survey, and as chairman of the Committee on Agriculture in Arid Regions he rendered service of national or international scope. In recognition of this service and of his numerous contributions to agricultural geology, plant physiology, soil physics and soil chemistry, he was awarded the Liebig Medal by the Munich Academy in 1894; a diploma and gold medal at the Paris Exposition in 1900; was elected honorary member of several scientific societies, and was given the honorary degree of LL.D. by the Universities of Mississippi, Michigan and Columbia. But while the world of science knew of his work and honored him for it, it was the peculiar privilege of his associates to find inspiration in his kind and helpful nature, in his catholic sympathies, in his clear vision and in his unflinching devotion to truth.

SOIL SCIENCE

RUTGERS COLLEGE.

Vol. I.

NEW BRUNSWICK, N. J., JANUARY, 1916.

No. 1.

INTRODUCTORY

Specialization must follow expansion in every field of knowledge. The growing mass of facts, observations and deductions must be classified, divided and subdivided. They must be made ready for the far sweep and insight of genius, ready for those broad generalizations that will fit the scattered and apparently unrelated parts into a symmetrical design. Without this preliminary gathering and grouping of facts, a task often tedious, at times seemingly unprofitable, the progress of science would be halted and the understanding of the great laws of nature would be dimmed.

Specialized technical publications are the necessary outcome of specialization in research. When investigation is carried on in a field of science but meagerly explored, the findings may be recorded in journals not specifically devoted to those problems. But as the data accumulate and the number of workers in a given field is increased the need becomes more urgent for a specific medium. That this need is now being felt in the field of soil research is attested to both by the large number of projects under investigation and the many specialists in the domains of soil physics, soil chemistry and soil biology. Scores of technical papers on the various phases of soil fertility appear in the course of each year as station research bulletins or in publications like the Journal of Industrial and Engineering Chemistry, the Journal of the American Society of Agronomy, the Journal of Agricultural Research, the Botanical Gazette, Science and a number of others. Many American contributions to soil science appear also in European journals, among them Centralblatt für Bakteriologie und Parasitenkunde, Zweite Abteilung, Internationale Mitteilungen für Bodenkunde and the Journal of Agricultural Science. It is evident, therefore, that under existing conditions the soil investigator is put to much inconvenience in keeping before him all of the more important papers in soil research. Moreover, he finds it increasingly difficult to secure the prompt publication of his own papers in journals whose contributions cover a wide range of scientific activity. Not infrequently six

months or more must elapse between the writing of a paper and of its appearance in print.

In planning for the publication of *SOIL SCIENCE* the Editor was guided by the wish to facilitate the bringing to light the results of soil-research. He felt encouraged to believe that the new journal would help to conserve the time and the energies of his fellow students of soils; that it would provide for a more direct contact among men interested in the same problems; and that it would lead to a broader outlook on the entire field of soil fertility. There need be no fear that *SOIL SCIENCE* will in any way impair the value or usefulness of other technical journals. From year to year there is a greater number research papers made available for publication in all the fields of science. As time goes on the older journals find it expedient to draw the lines of selection more rigidly and to give preference, within the greater volume of research problems, to one or another group of papers.

SOIL SCIENCE is to be devoted to problems in soil physics, soil chemistry and soil biology. Papers dealing with problems in plant physiology, agronomy, bacteriology or geology will be accepted only when they may contribute directly to our knowledge of soil fertility. It should not be assumed, however, that the field as outlined is at all a narrow one. The study of the mineral and organic constituents of soils, the study of soil gases, the study of soil water as a solvent of soil material, the study of soil colloids, the study of commercial plant foods and of their transformation in soils, all deal with questions as numerous as they are interesting. Added to these are the phenomena that concern soil micro-organisms, viz., bacteria, molds, protozoa and algae. Recent investigations in the domain of soil biology have shown us that this field is indeed a large one. If nothing else, these investigations have pointed out to us new modes of attack and have brought us appreciably nearer to a firmer grasp of the fundamental facts of soil fertility. It is the Editor's hope that *SOIL SCIENCE* will in some measure help to coordinate both methods and facts in soil research, and that the Consulting Editors, who so generously consented to lend their moral support to the new enterprise, will be amply repaid in the knowledge that they have made still another contribution to the progress of their chosen work.

THE EDITOR.

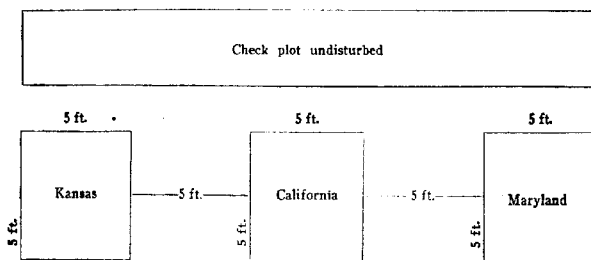
A DETAILED STUDY OF EFFECTS OF CLIMATE ON IMPORTANT PROPERTIES OF SOILS.*

By C. B. LIPMAN AND D. D. WAYNICK.

We owe to Hilgard more than to any other one investigator our prevalent conceptions with respect to the extremely important rôle played by climate as a determinant in the formation of soil types and, in a general way, of the productivity of the latter. Hilgard's admirable contributions to this subject, however, though based on a comprehensive survey of soil conditions the world over have dealt, in the main, with the causes underlying the physical and chemical constitution of soils as affected by climate. Even so far as those soil characteristics are concerned, the deductions and observations referred to, dealt with only some conditions as found at the time when the study was made, and particularly with regard to soil formation. They deal with changes wrought by the elements in agricultural soils themselves in periods of time measured secularly or millennially, rather than by intervals approximating the decade. There is as, a result, no information extant which may be employed to illuminate the subject of the effects of climatic changes, large or small, on the properties, in the broad sense of the word, of soils. It is to the task involved in such a study and in particular to changes wrought by climate in relatively brief periods of time in the same soil types that the authors addressed themselves. In planning the mode of attack in the case of such a problem, it occurred to the senior author that there was available a set of experimental soil plots which should lend themselves admirably to the purpose in view. These soil plots belong to the tri-state soil exchange experiment established for studies on climatic and soil effects on the gluten content, and on the composition, in general, of wheat. The latter experiment, which was initiated in 1908 is conducted under the joint auspices of the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture and the Departments of Agronomy respectively of the Maryland, the Kansas and the California Agricultural Experiment Stations. Detailed descriptions of the experiment are to be found elsewhere⁸ and need receive no further consideration here. It suffices for a clear comprehension of our experiments merely to state that a soil block, five feet square and three feet deep, from the fields of each of the three state experiment stations above named, was moved to the two other experiment stations and placed in position as nearly as possible in the original order of layers. A similar block of soil was dug up and replaced in its position at every station. Strips five feet wide of untouched field soil surrounded the board frame of every plot which was placed in position. It was then possible to

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study at Maryland, at Kansas and at California four soil blocks as follows: first, natural field soil *undisturbed*; second, natural field soil *disturbed* and replaced; third and fourth, soil blocks obtained respectively from each of the other two stations. The following diagram indicates the arrangement of these experimental soil blocks at the University Farm, Davis, California, and may typify the others as well.



From these plots soil samples for our experiments representing an average of each foot in depth were obtained from every station, except that through oversight no samples from the undisturbed soil at *Kansas* and at *Maryland* were obtained. The writers avail themselves of the opportunity offered in this connection to express their sense of obligation to Mr. M. A. Carleton, United States Department of Agriculture, Mr. Nickolas Schmitz, Maryland Experiment Station, Mr. F. A. Kiene, Jr., Kansas Experiment Station, and Messrs. J. W. Gilmore and B. A. Madison, of the California Experiment Station, who were instrumental in obtaining for them the soil samples from the several stations. It will be noted that a study of the samples of soil collected as above could not reveal the precise change undergone in seven years by any one soil when moved to any other station, because every one of the three soil types must have changed in its natural field position to some extent during that period. Nevertheless, such change it is only reasonable to assume, must be a relatively slight one as compared with that suffered by the same soil when removed and placed under totally different climatic conditions. Our investigations in any event can not be seriously affected by the consideration just discussed since it is our chief aim to show how any given soil in its natural location compares, after seven years, with itself under foreign conditions. Thus, for example, if the California soil at Manhattan, Kansas, or that at College Park, Maryland, now exhibits characteristics different from that now at Davis, California, the difference must be almost if not entirely referable to effects of climate. It is of course unfortunate that no detailed studies like ours, except the brief chemical studies discussed below, were made at the initiation of the soil exchange

experiment so that the data obtained therefrom might be used for comparison with our data. Finally, it must be repeated again at the risk of making this statement too prolix that it is possible to compare a given soil as it now exists at one station, at which it naturally belongs, with similar soil removed seven years ago and maintained during that period under other climatic conditions. The only permissible or possible comparison which would reveal the changes in any given soil in its natural position in a period of seven years is the one below made on the basis of its hydrochloric acid soluble constituents.

This is so because it is the only kind of study which was carried out in 1908 on the soils concerned. Even such a comparison is not without its serious drawbacks, since the chemical analysis made in 1908, or soon thereafter, was carried out by a different analyst and because the method employed was not as detailed nor quite the same as ours.

THE NATURE AND METHOD OF THE INVESTIGATION.

For the purpose of obtaining, as nearly as possible, a complete picture of the changes occurring in a soil when it is removed from one station to another with different climatic conditions as above explained, it was decided to study the important physical, chemical and bacteriological characteristics of the soil samples which were collected. The authors therefore determined to carry out the following studies, which may be supplemented with others later. Studies of the hygroscopic coefficient, the moisture equivalent, the wilting point, and changes in color and colloidal nature were among the physical studies made. Among chemical studies complete chemical analyses were made in accordance with the Official method, also humus and humus nitrogen determinations, total nitrogen and soil water-extract studies. Among bacteriological studies were: counts on albumen agar, ammonifying power for dried blood, nitrifying power for the soils own nitrogen, for dried blood, for cottonseed meal, for sulfate of ammonia, nitrogen fixing power in mannite solution, and qualitative tests for cellulose destruction by a method devised by the senior author. The results obtained in every class of studies are given in detail below, together with detailed descriptions of methods employed as deemed necessary.

DESCRIPTION OF SOILS.

The soils used in the experiments noted were described by Shaw and Walters ⁶ as follows: the California soil as "Sacramento silt loam," the Kansas soil as a "dark heavy loam" and the Maryland soil as a "light yellow clay." These terms are of little significance of course, especially since the soils have undergone so much change and such different changes at different places. So far as one of us knew them however, in the early part of the experiment, the California and Kansas soils seemed deserving

of names indicating a heavier and more tenacious condition than that indicated in the names above, and the Maryland soil of a designation indicating a much lighter condition than that of a clay soil.

THE PHYSICAL STUDIES.

The Hygroscopic Coefficient. The method employed in the determination of the hygroscopic coefficient was that recommended by Hilgard, and the apparatus employed was devised by one of the authors and described elsewhere.⁴ The determination both of the hygroscopic coefficient and the moisture equivalent were carried out by Mr. Donald E. Martin. The apparatus used for the moisture equivalent determinations is owned by the Division of Soil Technology, of the College of Agriculture of the University of California. We therefore take pleasure in expressing to Mr. C. F. Shaw, who allowed the use of his apparatus, and to Mr. Martin, who made the determinations, our appreciation of their cooperation. Table I gives the results of the hygroscopic moisture determinations.

TABLE I.
HYGROSCOPIC COEFFICIENTS.

Depth.	California Soil.			Kansas Soil.			Maryland Soil.		
	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.
	%	%	%	%	%	%	%	%	%
1st Foot.....	8.35	8.29	6.68	12.12	10.74	11.00	5.97	5.15	4.69
2nd Foot.....	8.67	7.69	8.44	12.42	12.38	11.68	6.82	5.82	7.66
3rd Foot.....	8.98	8.68	9.04	11.28	10.54	11.18	8.87	6.75	9.23

"Undisturbed" California Soil: 1st ft. 8.86; 2nd ft. 8.79; 3rd ft. 9.27

The results obtained with the hygroscopic coefficient determinations are not very striking. In general, it would appear that the California soil decreases in power to absorb hygroscopic moisture when placed either under Kansas or under Maryland conditions, but more particularly under the latter. In other words, the hygroscopic coefficient of the California soil is highest on its "native heath," as it were. In keeping with this general condition appears to be the behavior of the Kansas soil which when placed under California conditions increases in hygroscopicity in all three feet in depth. When placed under Maryland conditions, however, the Kansas soil behaves erratically and shows increase in hygroscopicity in the first and third foot in depth and a decrease in that respect in the second foot. In the case of the Maryland soil, the results are very irregular. Though the tendency seems to be for the Maryland soil to take up more hygroscopic moisture in California than in Kansas and in the surface foot more in Kansas than in Maryland, the soil in its natural location behaves otherwise below the surface. In general, however, the Maryland soil manifests a tendency in the same direction as the other

two, namely, to increase in hygroscopic power under California conditions. One would naturally expect that subjection of a soil to increased leaching would result in the production of more clay in it and hence render it more absorptive for hygroscopic moisture. The opposite, however, seems to be true. It seems that the explanation therefore would have to be as discussed more in detail below, that under arid conditions less clay and more aggregates being formed, the degree of packing is decreased and the total surface for hygroscopic moisture absorption is increased.

THE MOISTURE EQUIVALENT.

That the direction taken by the data given for the hygroscopic moisture coefficients of the soils in question is not purely accidental, is indicated rather emphatically by the results obtained in determining the moisture equivalents of the same soils (Table II). It will be noted again that the California soil at California is superior to the same soil at Kansas and at Maryland. In other words, it has a greater power there to retain moisture. Likewise, the Kansas soil throughout the three-foot depth retains about 3 per cent more moisture at California than at Kansas, but it also gains slightly in power to retain moisture through its establishment at Maryland. The figures for the Maryland soil are again irregular. In spite of their irregularity, however, there can be little doubt of the marked increase in power to retain moisture acquired by the Maryland soil in the seven years of its establishment at Kansas, and though it does not gain as much in that respect at California, such gain is none the less marked enough to allow of little doubt of its existence.

TABLE II.
MOISTURE EQUIVALENTS.

Depth.	California Soil.			Kansas Soil.			Maryland Soil.		
	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.
	%	%	%	%	%	%	%	%	%
1st Foot.	24.09	22.32	22.67	32.61	29.63	29.80	23.62	23.67	21.92
2nd Foot.	22.81	22.20	20.32	33.33	30.78	31.14	24.26	26.02	19.37
3rd Foot.	24.02	24.24	23.53	30.21	27.57	29.40	29.17	29.16	27.38

We have again, therefore and very much more markedly than before indirect evidence of increase in total soil surface which attends the placement for seven years of a soil under drier conditions than those under which it naturally belongs. This, it appears to us again, is contrary to what one would expect on a *priori* consideration, but is doubtless to be explained by the fact that, in general, drier climates encourage the formation of more aggregates in soils and hence permit of a looser structure and of a smaller weight of material in a given volume. Therefore, when soils are compared by equal weights it follows that more volume, hence more internal soil surface, would accompany the looser soil structure and that would result in a higher moisture equivalent.

THE WILTING POINT.

The table below which gives the wilting points is merely interesting for purposes of a more complete view of the properties of the soils here studied. It is not of great significance, or at least is not deserving of much discussion since the values therein indicated are obtained by computation from the moisture equivalent in accordance with the formula of Briggs and Shantz.¹

TABLE III.
WILTING POINTS.

Depth.	California Soil.			Kansas Soil.			Maryland Soil.		
	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.
	%	%	%	%	%	%	%	%	%
1st Foot.	13.09	12.13	12.32	17.72	16.10	16.19	12.83	12.86	11.91
2nd Foot.	12.39	12.06	11.04	18.11	16.72	16.90	13.18	14.14	10.52
3rd Foot.	13.05	13.17	12.78	16.41	14.98	15.98	15.85	15.84	14.88

OTHER OBSERVATIONS ON THE PHYSICAL CONDITION OF THE SOILS
STUDIED.

Color

Very marked changes take place in the color of a given soil when moved from one station to another, even in the short space of seven years. Thus the California soil changes from a distinct red brown color at California to a darker red brown at Kansas and to a dirty gray at Maryland. The three soils which seven years ago were exactly the same now show absolutely no similarity in color and as shown below very little similarity in many respects. Similarly, the Maryland soil changes from a light brown color in the surface foot at Maryland, to a dark brown in the corresponding depth at Kansas, and to a reddish brown color at California. Likewise, the Kansas soil changes in color from a deep black brown in the surface soil at Kansas to a light red brown at California and to a lighter ashen gray-brown at Maryland. These comparisons are based only on the surface soils in all cases, but the differences are so great as to mislead anyone unacquainted with these soils into thinking that any one type at the three stations is really not the same soil but three totally different soils unrelated to each other.

Colloidal Content and Volume of Soils

On this part of the soil studies, only preliminary observations have been completed. It appears thus far, that at their respective natural positions, the Kansas soil has the most volume per given weight, the California soil is second in that respect, and the Maryland soil last, but the latter two do not differ very markedly. When any one of these is placed elsewhere, however, great changes appear to take place in the volume of a given weight thereof even in seven years. The general tendency in that

respect, however, has not been fully enough studied to receive consideration here.

In respect to the colloidal fraction of a given weight of these soils when diffused in a large volume of water, great changes seem to be induced through climatic effects. Thus, for example, the Kansas soil at California shows much colloidal matter after 24 hours of suspension in the first foot, hardly any in the second foot, and none in the third foot. The same soil at Maryland shows a small amount of colloidal matter in suspension in the first foot, very much in the second foot, and almost none in the third foot. Again at Kansas the colloidal matter is not very marked at any depth, but much more so in the first and second foot than in the third. Similarly, as will be shown in a more detailed account to appear later, the other soils at different stations behave differently with respect to the colloidal matter in them which is capable of being suspended.

BACTERIOLOGICAL STUDIES.

Bacterial Counts.

Counts were made on all of the soil samples immediately after they were received. The medium employed was Brown's albumen agar. The figures obtained after the third count were taken as final and the numbers calculated for the three dilutions employed were averaged to yield the data submitted in Table IV which follows:

TABLE IV.
BACTERIAL COUNTS.

<i>California Soil.</i>						
	At California. No. per gram soil.		At Kansas. No. per gram soil.		At Maryland. No. per gram soil.	
	Bacteria.	Moulds.	Bacteria.	Moulds.	Bacteria.	Moulds.
<i>Series A.</i>						
1st Foot.....	1,820,000	14,000				
2nd Foot.....	169,333	20,000				
3rd Foot.....	108,666	20,000				
<i>Series B.</i>						
1st Foot.....	813,333	24,000	5,066,666	8,000	5,466,666	6,000
2nd Foot.....	414,666	4,000	2,140,000	8,000	926,666	2,000
3rd Foot.....	1,940,000	8,000	933,000	20,000	1,546,666	14,000
<i>Kansas Soil.</i>						
1st Foot.....	1,506,666	4,000	5,166,666	10,000	1,370,000	4,000
2nd Foot.....	1,680,000	12,000	6,100,000	None	610,000	8,000
3rd Foot.....	1,546,666	8,000	3,050,000	None	566,666	4,000
<i>Maryland Soil.</i>						
1st Foot.....	6,140,000	340,000	880,000	8,000	546,000	4,000
2nd Foot.....	800,000	200,000	210,000	6,000	400,000	2,000
3rd Foot.....	2,000	46,000	190,000	6,000	600,000	12,000

It is clear from the data in the foregoing table that even if allowance is made for the very serious errors which creep into work on bacterial counts, there is still evidence of the marked effect of climate on the number of bacteria in the several soils which will develop colonies on albumen agar. The data may be summarized as follows: The California soil in

its untouched field condition contains more bacteria in the surface foot than the same soil which has been dug up and replaced in its original position. In the second and third foot, however, and particularly in the latter, there are many more bacteria in the disturbed soil. Removal to, and retention for seven years of the California soil at Kansas and at Maryland have been instrumental in multiplying the bacterial numbers six to eight-fold in the surface foot of soil, the larger number being found in the soil at Maryland. In the second foot, however, the California soil at Kansas contains twice as many bacteria as the same soil at Maryland, but conditions are again reversed in the third foot.

Just as the California soil has its bacterial numbers enormously increased after remaining for seven years either at Kansas or at Maryland, the Kansas soil has its numbers reduced in about the same degree under similar circumstances as to time when placed either in California or in Maryland. The reduction in numbers is only slightly greater at Maryland than at California in the surface foot of soil, but is very markedly greater in both the second and the third foot of soil.

Again the Maryland soil gives unexpected results. The bacterial numbers in it increase to the greatest extent noted in all the data above submitted when it is placed and remains for some years in California. To be sure, this increase is only very marked in the first foot of soil, but it is very marked indeed. The number is only doubled in the second foot and a very striking decrease, hard to explain, occurs in the third foot. When the Maryland soil is placed at Kansas it also shows an increase in numbers in the first foot of soil, but the increase is by no means of the magnitude noted for the same soil at the California station. In the subsoil at Kansas, the Maryland soil suffers a marked decrease in numbers.

In general, therefore, it appears that the bacterial numbers in the California soil when placed at Kansas and at Maryland for the period of years noted become multiplied by four or five. Second, the bacterial numbers of the Kansas soil when placed as described at California or at Maryland become divided by four or five. Third, the bacterial numbers in the Maryland soil when placed under the conditions and time named at California and at Kansas become multiplied by ten in the surface foot at the former place, and approximately doubled in the surface soil at the latter station. In alphabetical order, therefore, the three different soils at California are approximately to one another with respect to bacterial numbers as 3 to 5 to 7. At Kansas they are about as 8 to 14 to 1, and at Maryland they are as 8 to $2\frac{1}{2}$ to $1\frac{1}{2}$, all figures being based on numbers of millions of bacteria in 3 gm. of soil representing three feet in depth.

The figures given for the number of moulds in the several soils may scarcely be regarded as significant with one exception, namely, the number of moulds in the Maryland soil at California. The cause for this sudden increase in the number of moulds under the circumstances noted

is probably incapable of being expressed in simple terms. It appears, however, that the increased aeration experienced by the Maryland soil at California may have been an important factor in developing inert fungal spores contained in it in large numbers.

THE AMMONIFICATION STUDIES.

The method employed in the ammonification work was the one in use by most soil bacteriologists to-day and consisted in mixing 50 gm. of soil with 2 per cent of dried blood, adding the necessary water and incubating for one week. The ammonia was distilled off in the usual way and titrated. Owing to the small amount of soil available no other forms of organic nitrogen were tested for ammonifiability in these soils.

TABLE V.
AMMONIFICATION OF DRIED BLOOD NITROGEN.

	California Soil.			In Kansas.			In Maryland.		
	c. c. acid	Mg. N ammoni- fied.	% N ammoni- fied.	c. c. acid	Mg. N ammoni- fied.	% N ammoni- fied.	c. c. acid	Mg. N ammoni- fied.	% N ammoni- fied.
<i>Undisturbed Check Soil.</i>									
1st Foot.	26.5	37.10	30.16						
2nd Foot.	28.2	39.48	32.09						
3rd Foot.	14.4	20.16	16.39						
<i>Disturbed Soil.</i>									
1st Foot.	28.1	39.34	31.98	38.9	54.46	44.27	27.9	39.06	31.75
2nd Foot.	18.8	26.32	21.39	23.0	32.20	26.17	22.1	30.94	25.15
3rd Foot.	16.2	22.68	18.43	17.3	24.22	19.68	18.3	25.62	20.82
<i>Kansas Soil.</i>									
1st Foot.	22.7	31.78	25.83	31.1	43.54	35.39	30.5	42.70	34.71
2nd Foot.	23.3	32.62	26.52	28.2	39.48	32.09	24.8	34.72	28.22
3rd Foot.	28.6	40.04	32.55	23.2	32.48	26.40	20.6	28.84	23.44
<i>Maryland Soil.</i>									
1st Foot.	27.2	38.08	30.95	34.3	48.02	39.04	29.7	41.58	33.80
2nd Foot.	22.4	31.36	25.49	21.5	30.10	24.47	20.5	28.70	23.33
3rd Foot.	20.2	28.28	22.99	19.2	26.88	21.85	19.1	26.74	21.74

A study of Table V, which sets forth the ammonification data which the authors obtained, reveals most strikingly of all the investigations thus far reported in this paper how significant a rôle is played by climate as a determinant of soil flora. We see first on studying the data more closely that by merely disturbing the California soil at its own natural location and replacing it no very profound changes are effected. Nevertheless such procedure does slightly increase the ammonifying power of the surface foot of soil and rather markedly decreases it for the second foot. The third foot gains slightly in ammonia producing power by being moved and replaced. When we now consider the effects on the ammonifying power of the California soil of seven years of exposure under California, Kansas and Maryland conditions respectively, we find them to be on the whole much more profound than those heretofore discussed. Thus contrasting the ammonifying power of the California soil similarly treated at

California and Kansas we find it to be very considerably larger at the latter location—indeed to the extent of being capable of rendering about 44 as against about 31 per cent of the nitrogen in dried blood into ammonia. The same climatic effects which have been instrumental in causing such a striking change in the ammonifying power of the first foot of the California soil at Kansas have extended their influence even into the second and third feet of the same soil at the same location. Thus the second foot renders over 5 per cent more and the third foot over 1 per cent more of the nitrogen supplied in the 2 per cent of dried blood into ammonia than do similar depths of the same soil which is located at California. In the case of the California soil which is installed at Maryland, however, we find relatively little difference in ammonifying power from that characteristic of the same soil in its natural location. Moreover, such differences as have made themselves apparent can be noted only in the second and in the third foot of the soil which resembles very closely in ammonifying power the corresponding depths of the same soil at Kansas.

Considering now the Kansas soil we find it to be a vigorous ammonifying soil in all three depths at Kansas. When, however, it is allowed to remain as above indicated for seven years at California, it loses markedly in ammonifying power in both the first and second foot of soil, though it gains in that respect in the third foot. The loss in ammonifying power suffered by the first foot of soil is not quite so great as the gain in that direction accruing to the California soil when similarly placed at Kansas, but is nevertheless decidedly of the same order of magnitude. Thus about 10 per cent more of the nitrogen in dried blood is ammonified in the Kansas soil at Kansas than in that at California; about 5 per cent more is thus transformed in the second foot of the Kansas soil at its natural location than at California. When however, the Kansas soil is placed at Maryland as explained, it suffers little modification in ammonifying power, if any, in the surface foot of soil, but does lose in that respect in the second and third foot.

In the case of the Maryland soil we are permitted again to gain an insight into the superiority of Kansas climatic conditions for increasing the ammonifying power of a soil over those of California and Maryland. Thus while at its natural location the Maryland soil is slightly inferior to the Kansas soil in ammonifying power, absolutely speaking, it becomes very considerably superior to it in that respect when placed at Kansas under the conditions noted. Even in the subsoil the ammonifying power of the Maryland soil is improved by its transfer to Kansas. When, however, the Maryland soil is placed at California, like the Kansas soil at the latter place, it loses in ammonifying power in the surface, though less slightly, and only in the surface soil. In the subsoil, it gains slightly in ammonifying power.

Studying now all of the figures in Table V, in the more absolute sense we find that the highest ammonifying efficiency attained by any of the soils there described is that of the California soil at Kansas and the Maryland soil at Kansas is second, when the surface foot of soil alone is considered. When the three-foot column of soil is considered, the Kansas soil at Kansas stands first in ammonifying efficiency and the California soil at Kansas second. Therefore, when the first foot alone is considered the Kansas soil at Kansas stands third and when the three-foot column is considered, the Maryland soil stands last.

At California the California soil is the most efficient ammonifier of dried blood nitrogen in the surface foot, but the Maryland soil at the same place is a close second with the Kansas soil decidedly behind. When, however, the three-foot column is considered the Kansas soil is first at California as it is at Kansas in ammonifying power, the Maryland soil is second, and the California soil is last.

At Maryland the Kansas soil is first in ammonifying efficiency in the first foot, the Maryland soil is second and the California soil last. The differences between the soils are here less marked, however, than at other places as above discussed. When the three-foot columns at Maryland are considered by averages the Kansas soil is first in ammonifying efficiency as it is at both California and Kansas, the Maryland soil is second and the California soil is last. In this respect therefore the three soils occupy similar relative positions to each other, both in California and in Maryland, and with one change for second place are also similarly situated at Kansas.

THE NITRIFICATION STUDIES.

The method employed in the nitrification studies is one which the senior author, in common with other investigators, has employed for several years. Briefly, it consists in studying the nitrifying power of 100 gm. of soil for a given form of nitrogen at an incubator temperature of about 28° C. during a period of about four weeks. In this case, however, the tests were more elaborate than usual, since four forms of nitrogen were employed, namely, the soil's own nitrogen (nitrogen in the untreated soil), cottonseed meal, sulfate of ammonia, and dried blood. In the first case 100 gm. of the air-dry soil were placed in a tumbler, enough water added to make as nearly as possible optimum moisture conditions, the whole thoroughly stirred, the tumbler covered with a Petri dish cover, and incubated as above indicated. In the case of the cottonseed meal the procedure differed from that just given only in that 1 per cent of cottonseed meal was thoroughly stirred into the soil in its dry condition before water was added. The dried blood cultures were similarly treated to the cottonseed meal culture, but in the case of sulfate of ammonia not 1 per cent but .2 per cent of the latter was added to the soil in solution

and the water content made up as described in the other cases. The results obtained showing the number of milligrams of nitrate nitrogen produced (net) in the four week's incubation period, together with the percentage of the total nitrogen present in the soil or the fertilizer, rendered into nitrate in every case, are set forth in Table VI which follows.

TABLE VI.
CALIFORNIA SOIL—NITRIFICATION.
In California, Series A (Undisturbed Soil).

	Soil Nitrogen.		Cottonseed Meal.		Sul. of Ammo'ia.		Dried Blood.	
	Mg. N nitri- fied.	% N nitri- fied.	Mg. N nitri- fied.	% N nitri- fied.	Mg. N nitri- fied.	% N nitri- fied.	Mg. N nitri- fied.	% N nitri- fied.
1st Foot.....	5.80	12.00	8.20	29.80	4.40	20.95	24.80	38.15
2nd Foot.....	3.83	9.11	7.83	28.46	2.83	13.49	11.83	18.20
3rd Foot.....	.95	2.61	5.35	19.44	3.55	16.95	14.85	22.84

In California, Series B (Disturbed Soil).

1st Foot.....	4.78	9.88	9.78	35.56	5.08	24.19	16.78	25.81
2nd Foot.....	3.90	9.60	lost	.....	4.30	20.47	16.90	26.00
3rd Foot.....	2.91	8.66	5.91	21.12	5.91	28.14	15.91	24.47

In Kansas.

1st Foot.....	4.64	10.35	19.64	71.41	2.24	10.66	.52	.80
2nd Foot.....	3.70	10.36	12.70	46.18	1.46	6.95	1.10	1.53
3rd Foot.....	2.50	8.71	14.70	53.45	1.46	6.95	.50	.77

In Maryland.

1st Foot.....	4.79	10.36	12.79	46.50	3.29	15.66	.79	1.21
2nd Foot.....	2.45	7.44	14.85	54.00	2.25	10.71	.15	.23
3rd Foot.....	2.72	8.44	13.92	50.61	1.92	9.14	.02	Trace

KANSAS SOIL.—NITRIFICATION.

In California.

1st Foot.....	4.33	6.72	13.93	50.65	19.93	94.90	23.93	36.81
2nd Foot.....	3.05	6.91	13.85	50.36	21.85	100.40	20.85	32.07
3rd Foot.....	lost	.....	19.70	71.63	21.70	100.30	8.70	11.84

In Kansas.

1st Foot.....	5.70	8.06	24.70	89.81	3.80	18.09	20.70	31.84
2nd Foot.....	4.20	8.95	21.60	78.54	5.60	26.65	4.10	6.30
3rd Foot.....	2.15	7.48	22.65	82.36	14.65	69.76	2.05	3.15

In Maryland.

1st Foot.....	5.86	9.73	24.86	90.40	3.86	18.38	3.66	5.58
2nd Foot.....	5.29	12.18	22.89	83.23	5.39	25.66	.89	1.36
3rd Foot.....	3.93	11.22	19.93	72.47	4.43	21.09	.33	.51

MARYLAND SOIL.—NITRIFICATION.

In California.

1st Foot.....	7.20	11.82	29.60	100.76	2.60	12.38	15.60	24.00
2nd Foot.....	.90	2.76	.65	2.36	1.90	9.04	20.90	32.15
3rd Foot.....	.90	2.79	— .20	.....	— .40	.....	1.60	2.46

In Kansas.

1st Foot.....	8.20	14.82	26.00	94.54	— .10	.....	4.00	6.15
2nd Foot.....	4.90	15.21	1.30	4.72	— .70	.....	— .50	.....
3rd Foot.....	2.20	6.98	— .70	.....	— .60	.....	— .60	.....

In Maryland.

1st Foot.....	7.78	15.65	10.78	39.20	— .22	.....	— .02	.....
2nd Foot.....	.93	3.24	.03	Trace	— .27	.....	— .17	.....
3rd Foot.....	.60	2.14	.35	1.27	— .15	.....	— .05	.....

The data submitted in the foregoing table are deeply interesting. They indicate very emphatically that climate plays a most significant rôle in determining the nitrifying powers of surface soils and of subsoils. They also show that the rôle thus played by climate may be in increasing or in diminishing a soil's nitrifying power by any given change in climate, depending upon the form and quantity of nitrogen which is being nitrified.

The California Soil—The Soil's Own Nitrogen.

Considering now in more detail data with reference to which the foregoing general statement is made, it is found first that while the disturbance and replacement of the California soil at California has caused a loss in the nitrifying power for its own nitrogen of the surface foot, it has caused a gain in that respect in the third foot; and the net result owing to the soil's disturbance is a considerable gain in the amount of nitrogen transformed into nitrate in three feet of soil. But even such improvement which probably results from increased aeration of the California soil at its own location is not as efficient in the respect noted as the establishment of the California soil at Kansas. At the latter place the California soil not only improves in nitrifying power in the sub-soil, but also surpasses its own record in the two surface feet of soil. At Maryland, however, while the nitrifying power of the surface foot of California soil is equal to that at Kansas, the second foot is considerably inferior to that of the same soil at the latter place. When, therefore, the three-foot columns of the California soil at the three stations are compared, that at Kansas is first, that at California second, and that at Maryland third in nitrifying power for the soil's own nitrogen. When, instead of comparing these soils on the basis of the percentage of nitrogen transformed into nitrate, we compare them on the basis of the absolute amounts of nitrate produced, the California soil at California stands first, that at Kansas is second, and that of Maryland is again third.

Cottonseed Meal Nitrogen.

The improvement wrought by the disturbance and hence aeration of the California soil at California, so far as its nitrifying power for its own nitrogen is concerned, is only intensified when its power to transform cottonseed meal nitrogen into nitrate is in view. This is true on the basis of the absolute amounts of nitrate produced as well as on that of the percentage of the total nitrogen in the cottonseed meal which is rendered into nitrate. Distinct as it appears to us to be, however, this degree of improvement in the direction noted in the California soil is greatly surpassed when compared with the improvement, both absolute and relative, which is induced by the establishment of the California soil at Kansas for the period here under consideration. The nitrifying power for cottonseed meal nitrogen of the California soil is so greatly improved

at Kansas that it transforms over 71 per cent of the total nitrogen in the cottonseed meal into nitrate in the surface foot of soil. This is among the most efficient transformations of cottonseed meal nitrogen noted by the writers in their nitrification work. When placed at Maryland, the California soil again gains very markedly in nitrifying power for cottonseed meal nitrogen, though not so markedly as it does at Kansas.

On the basis therefore of its power to render cottonseed meal nitrogen into nitrate, the California soil is to be appraised as follows: 1st at Kansas, 2nd at Maryland, 3rd at California.

Sulfate of Ammonia Nitrogen.

The disturbance of the California soil at California is instrumental even more markedly than in the case of cottonseed meal nitrogen in increasing its power to produce nitrate from sulfate of ammonia nitrogen in the third foot of soil. In striking contrast with the case of cottonseed meal nitrogen, however, the California soil when established at Kansas or at Maryland so far from gaining enormously in power to nitrify sulfate of ammonia nitrogen actually loses markedly in that respect at both places and particularly enough more markedly at Kansas than at Maryland. In other words, when sulfate of ammonia nitrogen is involved the nitrifying power of the same soil at the three different stations is in the following order the most efficient being placed first: 1st California soil at California, 2nd at Maryland, 3rd at Kansas.

Dried Blood Nitrogen.

When dried blood nitrogen is the form employed to test the soil's nitrifying power enormous changes, perhaps the most striking of all, are indicated by the removal of the soil to Kansas and to Maryland. Such changes are in the opposite direction to that noted in the case of the cottonseed meal nitrogen. Thus the California soil which when disturbed and aerated at California changes in nitrifying power for dried blood nitrogen much as it does for its own nitrogen there, still shows a good nitrifying power in either case. When, however, it is established at Kansas or at Maryland it almost loses in its entirety its power to nitrify dried blood nitrogen when the latter is employed in the quantity noted for the nitrification tests.

NITRIFICATION STUDIES—KANSAS SOIL.

The Soil's Own Nitrogen.

When placed at California the Kansas soil loses decidedly in nitrifying power for its own nitrogen, but when placed at Maryland it gains in that respect even more decidedly. This is just as true for the whole three-foot soil column as it is for any given sample. That the first should occur is intelligible to us and reasonably explicable on the basis

of changes in the organic matter content of the soil transported from Kansas to California. It is not clear how the latter occurs, however, unless we assume, which perhaps is true, that more organic matter has accumulated in the Kansas soil at Maryland than at its natural location. When, therefore, the California soil in three-foot columns is compared with the Kansas soil it is found that the former loses somewhat on the basis of absolute amounts of nitrates produced by being moved either to Kansas or to Maryland. The latter however, is improved markedly by its sojourn in Maryland and loses decidedly at California. In other words, climate does not seem to operate in the same direction, since the climate under which the California soil is most efficient as a nitrifier of its own nitrogen is the one under which in seven years the Kansas soil is rendered least efficient as among the three locations under which it was tested. Again, the California soil is least efficient in the direction noted under Maryland conditions, yet it appears that, of the three studied, the latter are the most propitious for the Kansas soil.

Cottonseed Meal Nitrogen.

Cottonseed meal nitrogen seems to be affected in a manner similar to that of the soil's own nitrogen in the Kansas soil, but differences in degree are decidedly apparent. Thus while the Kansas soil when placed at Maryland is perhaps slightly superior in nitrifying power to itself when allowed to remain in Kansas, such superiority is very slight. On the other hand, as a nitrifier of cottonseed meal nitrogen, the Kansas soil at California is decidedly inferior to that at Maryland or at Kansas. Both the absolute and relative amounts of nitrates produced from cottonseed meal nitrogen are especially worthy of note as indicating the high availability of the latter in that soil.

Sulfate of Ammonia Nitrogen.

The most noteworthy and only really remarkable figures obtained for the nitrification of sulfate of ammonia nitrogen were obtained with the Kansas soil at California. The absolute amounts of nitrates produced were so large as to indicate, if the soil nitrogen were not involved, an almost complete transformation of the ammonia nitrogen added into nitrate in the whole three-foot columns. The figures given there as well as in one or two other places in the table which show more than 100 per cent availability of nitrogen are of course to be explained on the basis of a nitrification of the soil nitrogen plus the added ammonia nitrogen. Since such a sum is usually an algebraic one, it may readily be inferred that even more nitrates may have been produced in the cultures concerned and again lost sometime during the incubation period. Briefly, therefore, as the table indicates and just contrary to the cases of the soil's nitrogen and that of the cottonseed meal, the Kansas soil gains very markedly in nitrifying power for sulfate of ammonia nitrogen by being

placed at California. In the third foot, however, while the Kansas soil at California is still far superior to that at Kansas in the direction noted, the latter shows great activity. At Maryland, however, the Kansas soil is even a relatively less efficient nitrifier of sulfate of ammonia nitrogen than at Kansas, and in the third foot decidedly less so.

Dried Blood Nitrogen.

In respect to dried blood nitrogen, the Kansas soil, as to location, acts in a manner similar to its action with sulfate of ammonia nitrogen. In other words, it nitrifies blood nitrogen more efficiently at California than it does at its own natural location in the whole three-foot column, but particularly in the subsoil. On the other hand, when it is moved to Maryland it loses, even more strikingly than in the case of sulfate of ammonia nitrogen, its power to produce nitrates from dried blood nitrogen. At the latter place, indeed, its nitrifying power for dried blood nitrogen is feeble in the surface foot of soil and almost nil below.

NITRIFICATION STUDIES—MARYLAND SOIL.

The Soil's Own Nitrogen.

The table above submitted indicates that there can be no question about the profound effect of the Kansas climate on the nitrifying power of the Maryland soil for its own nitrogen, particularly so far as the subsoil is concerned. Thus of the total nitrogen found in the three-foot column of the Maryland soil at Kansas, over 37 per cent is nitrified, whereas of the total nitrogen in the same soil at Maryland (its natural location) only about 21 per cent is nitrified. At California, on the other hand, the nitrifying power of the Maryland soil remains practically unchanged, from its condition at Maryland. The surface soil does seem to lose in nitrifying power slightly, but no conclusions may be drawn from that fact.

It is to be particularly remarked here, however, that the nitrogen of the Maryland soil is far more readily nitrified than that of the Kansas and California soils, even though we are obliged to draw this conclusion from the data for the surface foot of soil only.

Cottonseed Meal Nitrogen.

Unlike the Kansas and the California soils, the Maryland soil does not show parallelism in general direction between its power to nitrify cottonseed meal nitrogen and its own nitrogen. Thus at California the Maryland soil nitrifies cotton seed meal nitrogen more efficiently than at Kansas, and does nearly three times as well at the first mentioned place as it does at its natural location in Maryland. It is worthy of note also that while the soil's own nitrogen in the Maryland soil at Kansas is readily nitrified in the subsoil, the same soil from the same place shows only a feeble nitrifying power for cottonseed meal nitrogen, despite the fact that

the latter nitrifies very much better than the soil nitrogen in the first foot of soil. It is further to be remarked that the maximum absolute amount of nitrate obtained in any of the cultures reported in the foregoing table was obtained in the Maryland soil at California, and that at Kansas was a close second. These records are, to be sure, made only in the first foot of soil. We may also add that the percentage of total nitrogen transformed in the two record cultures referred to are above 100 per cent and above 94 per cent respectively. These figures are of course somewhat exaggerated since they represent nitrates produced from the soil nitrogen as well as that from cottonseed meal nitrogen, but the latter alone was used in the calculation above made. The reason as explained above for not subtracting the amount of nitrate produced from the soil nitrogen from the total obtained in the cottonseed meal cultures is that the latter amount represents the algebraic and not the arithmetical sum of nitrification activities in those cultures. For the first time among all the cultures discussed in the nitrification studies we are confronted by a subsoil in the Maryland soil at all stations which is either very feeble in nitrifying power or possesses none at all for cottonseed meal nitrogen.

Sulfate of Ammonia Nitrogen.

Among the most striking results obtained with the Maryland soil are the nitrification figures for sulfate of ammonia nitrogen. Not only is the Maryland soil at both Maryland and Kansas incapable of nitrifying sulfate of ammonia nitrogen in the quantity used, but the addition of sulfate of ammonia actually causes a loss of the nitrate nitrogen initially contained in the soil. At California, on the other hand, the Maryland soil has evidently become so changed in seven years as to be capable of nitrifying sulfate of ammonia nitrogen in both the first and second feet, though losing nitrates as in the other cases, in the third foot. The absolute and relative magnitude of the transformation of the ammonia nitrogen in question into nitrate in the Maryland soil at California is approximately that of the California soil at Kansas, and considering the first two feet of soil alone is probably slightly better. The acid condition of the Maryland soil is probably chiefly responsible for its behavior with respect to sulfate of ammonia.

Dried Blood Nitrogen.

At Kansas and at its natural location the Maryland soil behaves with respect to dried blood nitrogen very much as it does toward sulfate of ammonia nitrogen, except that it does nitrify the former to some extent in soil from the first foot at Kansas. Likewise, at California there is a similar behavior, in kind between the Maryland soil with blood nitrogen and ammonia nitrogen. In degree, however, there is a marked difference, the blood nitrogen being much more vigorously nitrified in the first two

feet of soil than the sulfate of ammonia nitrogen and even in the third foot of soil it is appreciably nitrified. So far as dried blood nitrogen is concerned, therefore, the Maryland soil is clearly improved in the first foot in nitrifying power by being placed at Kansas, and very markedly improved in the whole soil column in that respect by being placed for the same period of seven years at California. The possible causes of the non-nitrification of blood nitrogen in the Maryland soil at some places and its ready nitrification in other places are discussed elsewhere in this paper.

MANNITE SOLUTION AND NITROGEN FIXATION STUDIES.

Owing to the small quantity of soil available we were compelled to use the mannite solution method for determining the nitrogen fixing powers of the soil. It is of course regrettable that the soil itself could not be employed as a medium, as was the case in other tests above noted. The data obtained, however, are very interesting and the method employed, while defective in some respects, is valuable in that the Azotobacter and other bacterial forms involved could be studied more in detail thereby, as the descriptions below indicate. The cultures which were incubated for two weeks were prepared by inoculating 5 gm. of the soil to be tested into 50 c.c. mannite solution. The nitrogen determinations were made by the modified Gunning method in use in this laboratory and a description of it may be found elsewhere.³ The results of the observations made after one and after two weeks' incubation on every culture were as follows:

CALIFORNIA SOIL.

"Undisturbed."

- First Foot.* Butyric odor, very few azotobacter cells visible under microscope. Gas formation marked. Membrane slow to develop. Same after two weeks.
- Second Foot.* Slightly esteric odor, good azotobacter development. Gas formation marked. Membrane thin, mucilaginous. Same after two weeks.
- Third Foot.* Odor more markedly esteric than that of second foot. A few azotobacter cells. Membrane slight. Gas formation marked. Same after two weeks.

Disturbed.

- First Foot.* Fairly strong esteric odor, also slightly butyric. A few azotobacter cells. Membrane slow to develop. Gas formation marked. Same after two weeks, but less cells.
- Second Foot.* Esteric odor. Few azotobacter cells. Slight membrane. Gas formation marked. Same after two weeks.
- Third Foot.* Odor same as above. Membrane very heavy and mucilaginous. Azotobacter numerous. Gas production marked.

At Kansas.

- First Foot.* Slightly fetid, also esteric odor. Heavy membrane, granular. Little, if any, gas formation. *A. chroococcum* very plentiful. Pigment marked, brown-gray; same after two weeks, but deeper color.
- Second Foot.* Odor same as above. Membrane not granular but continuous, dark, silver gray pigment. Very little *A. chroococcum*, if any, visible. Other azotobacter forms. Gas formation same as above. Same after two weeks.
- Third Foot.* Odor same as above. Membrane same as first foot, but pigment light silver gray. *A. chroococcum* as in first foot. Gas formation same. Same after two weeks.

At Maryland.

- First Foot.* Fetid odor almost masks strong butyric odor. Heavy membrane. Pigment brownish gray. Very little gas formation. *A. chroococcum* not as numerous as in same soil at Kansas. Other azotobacter forms numerous. Same after two weeks, except pigment dark brown to black.
- Second Foot.* Same odor as first foot. Membrane same but pigment silver gray. Almost no gas. Azotobacter forms as in first foot. Same after two weeks.
- Third Foot.* Odor and membrane as in first foot. Pigment, however, is yellowish. Heavy gas formation. Azotobacter as in first foot. Same after two weeks.

KANSAS SOIL.

At California.

- First Foot.* Mild esteric odor. Many azotobacter cells, but no membrane. Gas production marked. Same after two weeks.
- Second Foot.* Mild esteric odor. Very many azotobacter cells, but no membrane. Gas production marked. Same after two weeks.
- Third Foot.* Mild esteric odor. Only few azotobacter cells. No membrane. Gas production marked. Same after two weeks.

At Kansas.

- First Foot.* Decidedly fetid odor. Good membrane. Pigment none, but gray color. Moulds present on membrane. No gas. Same after two weeks, except odor not so strong, much more mould and blue to purple color appearing.
- Second Foot.* Strong, pleasant, esteric odor. Membrane same as in first foot. Azotobacter present in both. Color light silver gray. No pigment. No gas. No mould. Same after two weeks.
- Third Foot.* Same as second foot, but color is yellowish gray. No mould.

At Maryland.

- First Foot.* Fruit and nut odor. Very heavy membrane. No gas. Several species of Azotobacter appear to be present. Much mucilaginous material in membrane. Slightly dark pigment after two weeks.
- Second Foot.* Same as first foot except distinct azotobacter species appear to be present in addition. Not as much mucilaginous material in membrane. Odor weaker. After two weeks very dark pigment.
- Third Foot.* Same as first foot, but gas present and pigment more marked. After two weeks gas has disappeared and moulds appearing.

MARYLAND SOIL.

At California.

First Foot. Strong butyric odor. Clostridium plentiful, but no Azotobacter. Membrane superimposed on gas bubbles made up of fungus mycelium. Same after two weeks.

Second Foot. Weak esteric odor. Clostridium present, but no Azotobacter. Membrane superimposed on gas bubbles, as in first foot. Same after two weeks.

Third Foot. Weak esteric odor. Clostridium found, but no Azotobacter. Heavy mould membrane. Same after two weeks.

At Kansas.

First Foot. Butyric odor. No membrane. Gas formation plentiful. No moulds. No azotobacter forms visible. After two weeks the same, except a few cells found which resemble Azotobacter.

Second Foot. Odor somewhat esteric, but different from any thus far noted. Less marked gas formation than above. No Azotobacter. No moulds. After two weeks odor changed to that of mercaptan. Heavy algal growth also has appeared.

Third Foot. Much the same throughout as second foot.

At Maryland.

First Foot. Strong butyric odor. Clostridium forms plentiful. No membrane. Fair gas production. A few cells resembling Azotobacter. No pigment. No color. After two weeks a little more gas formation, but otherwise the same.

Second Foot. Same as first foot, except bacteria more numerous and show more activity.

Third Foot. Same as first foot.

THE NITROGEN FIXATION DATA.

Before discussing the actual and probable significance of the data on the mannite solution cultures which are above set forth it may be well to consider the data obtained with the same culture as regards nitrogen fixation. The nitrogen was determined as above stated after the two weeks' incubation period and the amounts of nitrogen found in the cultures as well as that actually fixed from the atmosphere are given in Table VII which follows.

It is interesting to note by way of general correlation of the chemical data with the microscopic and macroscopic observations on the mannite solution cultures, that a parallelism exists between the magnitude of the amounts of nitrogen fixed and the presence or absence of Azotobacter. Very vigorous azotobacter membrane development is always accompanied by high nitrogen fixation. Per contra, slight membrane formation or relative scarcity of azotobacter cells is always associated with low nitrogen fixation. Nevertheless, even the total absence of azotobacter organisms as is clearly brought out above does not prevent the soil from fixing nitrogen, though the amounts fixed may be much smaller

than is the case in the presence of those organisms. This observation is in harmony with a similar one previously made by the senior author in other mannite solution studies.* Not only the presence of *Azotobacter*, but also the thickness of the membrane, and the rapidity of its development are excellent indicators of the degree of nitrogen fixation.

TABLE VII.
NITROGEN FIXATION IN MANNITE SOLUTION.

California Soil (Disturbed).

	In California.		In Kansas.		In Maryland.	
	Mg. N found	Mg. N fixed per gram mannite	Mg. N found	Mg. N fixed per gram mannite	Mg. N found	Mg. N fixed per gram mannite
1st Foot.....	8.82	3.92	14.28	9.80	14.28	9.66
2nd Foot.....	8.54	4.48	12.04	8.54	12.32	9.10
3rd Foot.....	8.54	5.18	13.58	10.78	12.88	9.66
<i>Undisturbed.</i>						
1st Foot.....	8.96	4.20				
2nd Foot.....	9.38	5.18				
3rd Foot.....	7.84	4.20				

Kansas Soil.

1st Foot.....	6.58	.14	16.94	9.94	16.66	10.64
2nd Foot.....	8.40	4.06	13.16	8.54	14.98	10.64
3rd Foot.....	10.50	7.28	11.90	9.10	13.02	9.52

Maryland Soil.

1st Foot.....	9.52	3.50	8.96	3.50	10.22	5.32
2nd Foot.....	6.44	3.22	7.56	4.34	8.12	5.32
3rd Foot.....	6.30	3.08	7.28	4.20	6.16	3.36

When more specifically discussed, the data submitted offer numerous points of interest. The disturbance of the California soil without any other modification reduces nitrogen fixation and *azotobacter* development in the first and second foot and increases it in the third foot. Removal of the California soil to Kansas increases the vigor of the *azotobacter* flora and especially that of *A. chroococcum* and increases the nitrogen fixation by 50 per cent of that attained by the same soil at California. Removal of the California soil to Maryland is nearly, if not quite, as efficacious a measure for invigorating the *azotobacter* flora and increasing nitrogen fixation as the removal of the soil to Kansas.

The Kansas soil at Kansas shows a vigorous *azotobacter* flora and gives evidence of vigorous nitrogen fixing power. With the exception of the third foot which does not fix as much nitrogen, the Kansas soil at Kansas is about equally good at nitrogen fixation with the California soil at Kansas. When, however, the Kansas soil is removed to California and remains there as observed, it loses its power to produce a membrane in mannite solution, the *azotobacter* flora become rather feeble and the number of cells few and nitrogen fixation power is reduced to almost nothing in the first foot, by more than 50 per cent in the second foot, and by about 20 per cent in the third foot. These data were so striking that the

cultures were repeated with new soil obtained from the same plots. Similar results were obtained and they differed only in that the first foot fixed .70 mg. instead of .14 mg. nitrogen, and in that membranes were formed in the second and third foot and nitrogen fixation was correspondingly increased there. Even in this more favorable series of cultures the fixation of nitrogen was very much lower in the Kansas soil at California than in that at Kansas. Since the second set of samples was taken at a different season the results therewith are not strictly comparable with those above submitted, and they are therefore not given here. Removal of the Kansas soil to Maryland so far from inducing deterioration and enfeeblement of the azotobacter flora as was the case in removing that soil to California, actually increases the vigor of those organisms and conduces to the fixation of more nitrogen than that accomplished by that soil at its home location. Indeed, the greatest fixation of nitrogen in any of the cultures is accomplished by the Kansas soil at Maryland when the whole three-foot column is considered. The cause for the behavior of the Kansas soil at Maryland is not easy to discover. It is probably to be found in some of the intricate relationships induced in soils by climate which will be discussed, in general, below.

The Maryland soil at Maryland has a slightly higher nitrogen fixing power than the California soil at California, despite the fact that the latter has a relatively feeble azotobacter flora and that the former probably has no azotobacter organisms. Still the difference is very slight when the whole three-foot column is considered, and the very vigorous *Clostridium* flora in the Maryland soil probably offset the activity of the feeble azotobacter flora in the California soil. However, that may be, the case under discussion is no serious objection to the correlation drawn above between nitrogen fixation and the presence of vigorous azotobacter flora since from the absolute standpoint the nitrogen fixation (in mannite solution) in both soils here discussed is decidedly low. When the Maryland soil is placed at California it appears to lose in nitrogen fixing power as does the Kansas soil when similarly placed, but not so markedly as the latter. Moreover, it develops very vigorous mould flora which does not appear to be present in the same soil at its home site. This mould flora forms a veritable thick membrane at the surface of the mannite solution which is observed nowhere else in the cultures here discussed. Whether the decrease in nitrogen fixation is caused by an enfeeblement of the *Clostridium* flora through increased aeration or is in some way connected with a loss of nitrogen through the heavy mould development is impossible at this time to state. By reference to the tables given below it will be seen that another puzzling element enters into this problem. The Maryland soil seems to gain appreciably in total nitrogen through its sojourn in California during a stated period. Whether, in connection with the

nitrogen fixation data above considered this be a causal relationship or merely one of effect remains also an open question. At Kansas the Maryland soil also loses in nitrogen fixing power but not nearly as much and it even shows an appreciable gain in the third foot. In this case the question of mould development does not enter in as observed in the description above given. On the other hand a vigorous algal development principally of Cyanophyceae is noted in the second and third foot. Since algae have been on many other occasions shown to be more or less directly connected with stimulation to non-symbiotic processes of nitrogen fixation, their presence, particularly in the third foot of Maryland soil at Kansas, may not be without significance. In general, however, and as a soil column the Maryland soil loses in nitrogen fixing power by being removed either to California or to Kansas. Since its nitrogen fixing powers are probably entirely dependent or nearly so, on *Clostridium* and other anaerobic non-symbiotic nitrogen fixing organisms, the observed facts are probably explicable on the ground of the increased aeration given the soil at both California and Kansas, which would operate towards the inhibition of the activities of the organisms mentioned.

The long period of drouth and loss of organic matter suffered by all the soils at California is probably also responsible for the partial destruction and hence enfeeblement of the nitrogen fixing flora. This might perhaps help to explain not only the facts noted in the case of the Maryland soil just discussed, but also that of the Kansas soil and the striking results obtained with it at California. On the other hand, the same idea would explain the increase in activity as regards nitrogen fixation manifested by the California soil at Kansas and at Maryland and by the Kansas soil at Maryland on grounds of differences in the amount and distribution of precipitation which are too well known to need amplification here.

It is hoped that further investigations now in progress will demonstrate whether or not the observations made above together with general observations to be made below are adequate to explain the facts set forth with reference to nitrogen fixation. Irrespective of that, however, it appears to be certain from the data thus far in hand, that the nature of the nitrogen fixing flora of a given soil and characteristics pertaining thereto, are not to be accounted for under the conditions here studied, by a mere contamination of one soil by another, in the experiment described, for which there has been given the most ample opportunity. Such may appear to be the case, for example, when the nitrogen fixation attained by the Kansas soil at Kansas and the California soil at Kansas are compared. The idea fails of substantiation, however, when we observe that the California soil at Maryland does not exhibit characteristics of the Maryland soil at Maryland, but rather those resembling the Kansas soil at Kansas. Likewise the Maryland soil at Kansas does not behave as

the Kansas soil at Kansas, but more closely resembles in behavior the California soil at California. So too, if we may be allowed another example to illustrate the point we are attempting to make, the Kansas soil at California does not at all resemble the California soil at that place in respect to nitrogen fixation, and indeed behaves unlike any other soil there, it being the only soil that in the surface foot fixes scarcely any nitrogen.

STUDIES ON CELLULOSE DESTRUCTION.

The method employed for comparing the cellulose destroying powers of the soils here studied was not a quantitative one, but consisted of the following procedure. Thirty grams of soil were placed in a Petri dish and smoothed off on the surface as much as possible. A little more moisture than was necessary for optimum conditions was then added after placing a disk of ashless filter paper on the soil surface. This procedure insured almost uniform contact of filter paper and soil. The dishes were then covered and incubated at 28° to 30° C. for four weeks. Most of the cellulose destruction noted was carried out in the first eight or ten days. The results obtained are set forth in the photographs which are submitted herewith in Plates I, II, III, IV, and V.

A study of the photographs brings out very strikingly the relationships obtaining between the various soils and cellulose destruction. Not only is the surface foot of the California soil more vigorous at cellulose destruction than the corresponding depth of the Kansas or the Maryland soil, but the second and third foot thereof are very vigorous in that respect, whereas, corresponding depths of the other soils have dissolved none or scarcely any portion of the filter paper. Moulds also are very much more numerous in the California soil of the Petri dishes. It is also to be seen from the photographs that the characteristic efficiency at cellulose destruction of the California soil while somewhat abated by its removal to other climates, is none the less still clearly persisting there. A part of this observation is entirely in accord with the results of McBeth's painstaking studies on cellulose destroying organisms and their comparative effects in soils from different climates, a fuller account of which than heretofore given is soon to appear.⁷

Considering the plates above referred to a little more in detail, it is of interest to follow the changes in capacity to dissolve cellulose which appear to result from the removal of a soil from its own climate to another. In making such comparison it should be borne in mind that at the beginning of the experiment the surfaces of all the Petri dishes looked alike and indeed very much like No. 6 in either Plate D or Plate E, or perhaps of even more uniform whiteness. A glance at Plate A, which portrays the six soil samples from California of the California soil shows the marked power possessed by these soils to dissolve cellulose. This power

appears to be as marked in the "disturbed" soil at California as in the "undisturbed" soil or at least the qualitative method here employed allows of the detection of no difference between the two. It is striking to note moreover in Plate A that the second and third foot of the California soil at California dissolves cellulose as vigorously as does the first foot.

In striking contrast with the behavior of the California soil at California as regards cellulose dissolution as portrayed in Plate A is the behavior of the same soil at Maryland and at Kansas in respect to the same factor as illustrated in Plate B. Not only does the California soil at Maryland exhibit an extremely feeble power to dissolve cellulose in the first foot, but such power is virtually non-existent in the second and third foot. In other words, removal of the California soil to Maryland and its sojourn there for seven years have been instrumental in depriving it almost entirely of its cellulose destroying powers. At Kansas the California soil has not fared so badly in the surface foot and still shows itself fairly vigorous at the destruction of cellulose. But in the second and third foot and particularly in the latter, the solvent power of the soil for cellulose is extremely feeble and possibly wanting. The black blotches in Figs. 5 and 6 of Plate B, are contaminating moulds with no solvent effects on cellulose. Such black blotches are not to be confused with the dark soil color showing through the paper as in Fig. 4, Plate B.

A study of Plate C shows that the Kansas soil becomes more active at cellulose destruction in the first foot as a result of its removal to California. Owing to the black mould which contaminated Fig. 2 in Plate C, it is impossible to say if the effect just described has descended to the second foot or not. At its home location for some unaccountable reason the Kansas soil has but little cellulose destroying power in the second foot, and yet shows a fair power in that direction in the third foot. It does not possess such power in the third foot at California. At Maryland the Kansas soil, like the California soil, appears to have lost almost in its entirety its cellulose destroying power, though possibly a remnant thereof still remains in the surface foot. These observations are borne out by Figs. 4, 5 and 6 in Plate D.

Plate D, Figs. 1, 2 and 3 illustrate the behavior in respect to cellulose destruction of the Maryland soil at California in which cellulose destruction is fairly vigorous particularly in the first two feet and slight in the third foot. When one contrasts the foregoing with Figs. 1, 2 and 3 on Plate E, which exemplifies the results obtained with the Maryland soil at Maryland, it becomes clear how strikingly altered in the respect noted the Maryland soil at California has become. From a feeble power or none at all to destroy cellulose, it has developed at California a fairly vigorous power. At Kansas the Maryland soil has also attained some power at cellulose destruction in the first foot. In the second and third foot it has remained virtually unchanged even at Kansas. Even in the

first foot its cellulose destroying power is not as great as at a corresponding depth of the same soil at California.

THE CHEMICAL INVESTIGATIONS.

There will be found in the introduction to this paper an account of the general plan of the chemical investigations. The most important of these was of course the analysis by the official strong acid digestion method of every soil represented in these studies. The results obtained in these studies are therefore given first and include besides the analysis of the hydrochloric acid extracts for the constituents noted, the determinations of phosphoric acid by the nitric acid extraction method (gravimetrically) and the determination of potash by the perchloric acid method as modified by Davis.² The results are given in Table VIII.

In order to compare the different constituents shown by analysis of the different soils, as variously placed, to best advantage we shall consider every cognate group separately so far as possible.

Insoluble and Soluble Silica.

In general the data for insoluble and those for soluble silica as obtained by us for the different soils appear to be in harmony with Hilgard's observations on the effects of climate on the constituents of soils here under consideration. In some respects however, our data are at variance with Hilgard's on the same subject. Specifically, we find that the California soil remains virtually unchanged with respect to its content of silica (both insoluble and soluble) when it is disturbed for three feet in depth, but again replaced in the same position. When, however, it is placed at Kansas it gains very markedly in its content of insoluble silica and loses as markedly with respect to its soluble silica content. The Maryland climate seems to exert its effects again irregularly. For example the California soil while not gaining nearly as much there in insoluble silica as it does at Kansas still shows a very appreciable gain over the same soil at California, but it also gains very appreciably in soluble silica whereas the opposite effect would naturally be expected.

Unexpectedly, again the Kansas soil gains in insoluble silica when placed at California, though to be sure the gain is not great. In soluble silica, again the unexpected occurs and there is a marked decrease in that constituent when the Kansas soil is placed at California. When placed at Maryland, on the other hand, the Kansas soil remains practically unchanged with respect to insoluble silica, but loses very appreciably in its soluble silica content. All of these observations are of course made on the basis of the three-foot columns.

The Maryland soil is characteristically and expectedly high in insoluble silica and low in soluble silica. It is very slightly changed in either respect by being placed at either California or at Kansas. Some changes

worthy of mention do however occur. For example, the insoluble silica appears to remain unaltered in quantity in the Maryland soil or virtually so by its placement at California, but a distinct increase in soluble silica is clearly accompanied therewith. On the other hand, at Kansas the Maryland soil increases appreciably in insoluble silica and suffers a decrease in soluble silica. It will be remembered that the California soil is similarly affected at Kansas, except more strikingly.

TABLE VIII.
CHEMICAL ANALYSES OF SOILS STUDIED BY OFFICIAL METHOD.

	California Check.			Cal. in California.			Cal. in Kansas.			Cal. in Maryland.		
	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.
Insol. Sil.	%	%	%	%	%	%	%	%	%	%	%	%
Sol. Sil.	60.31	61.21	61.82	61.98	61.04	60.70	70.01	68.70	75.20	63.23	64.20	65.30
K ₂ O	13.09	15.88	16.94	11.78	13.12	17.93	7.73	10.88	6.80	16.92	16.36	15.14
Na ₂ O	.51	.42	.51	.47	.49	.43	.41	.51	.47	.42	.47	.43
CaO	.58	.66	.59	.59	.72	.61	.79	.74	.75	.74	.87	1.96
MgO	.....	2.83	.89	1.36	3.40	1.48	1.23	3.35	2.56	1.15	1.75	1.08
Mn ₂ O ₄	.18	.18	.14	.18	.12	.18	.46	.51	.40	.52	.65	.28
Fe ₂ O ₃	7.99	8.43	8.14	9.00	7.99	8.88	2.22	3.55	3.70	6.36	3.25	5.62
Al ₂ O ₃	4.24	7.27	3.18	4.80	7.99	2.86	12.46	6.85	5.88	4.20	8.59	5.46
P ₂ O ₅	.13	.14	.13	.12	.13	.14	.17	.17	.16	.15	.17	.17
SO ₃	.10	.12	.09	.10	.10	.08	.10	.06	.05	.14	.11	.09
Volatile matter	.....	2.37	6.49	8.66	4.65	6.43	4.18	4.63	4.27	5.39	3.17	4.22

	Kansas in Cal.			Kan. in Kansas.			Kan. in Maryland.		
Insol. Sil.	64.52	63.33	61.44	63.85	60.40	60.81	60.66	61.92	62.32
Sol. Sil.	13.64	15.94	17.80	18.28	18.74	17.74	15.16	14.54	13.73
K ₂ O	.61	.58	.81	.68	.71	.83	.59	.62	.74
Na ₂ O	.61	1.30	2.06	.84	1.08	1.66	1.08	.66	.66
MgO	.95	.94	.78	.92	1.01	.91	3.84	2.33	4.66
Mn ₂ O ₄	.14	.13	.13	.61	.43	.....	.28	.36	.23
Fe ₂ O ₃	6.95	6.66	5.47	3.40	3.40	2.96	6.95	4.19	8.73
Al ₂ O ₃	5.67	5.98	8.43	8.14	10.76	10.84	6.85	9.41	5.39
P ₂ O ₅	.11	.13	.10	.15	.13	.15	.15	.14	.12
SO ₃	.11	.09	.07	.11	.10	.17	.11	.12	.12
Volatile Matter	6.08	4.39	2.35	2.26	2.41	3.64	3.60	4.83	2.84

	Maryland in Cal.			Md. in Kansas.			Md. in Maryland.		
Insol. Sil.	79.10	78.31	83.01	84.08	80.24	81.88	81.88	73.87	79.96
Sol. Sil.	6.80	7.58	.....	8.13	5.73	5.89	5.89	11.18	3.39
K ₂ O	.24	.16	.28	.31	.26	.19	.28	.31	.28
Na ₂ O	.....	.....	.....	.....	.....	.....	.....	.....	.....
CaO	.28	.22	.20	.26	.15	.20	.20	.15	.13
MgO	.51	.38	.18	.28	.29	.21	.21	.23	.19
Mn ₂ O ₄	.16	.19	.12	.12	.11	.16	.16	.06	.10
Fe ₂ O ₃	6.06	6.95	7.54	2.66	2.96	2.81	2.81	2.51	2.79
Al ₂ O ₃	2.73	3.65	4.62	6.22	7.76	7.35	7.35	7.95	9.97
P ₂ O ₅	.10	.14	.17	.10	.15	.11	.15	.09	.13
SO ₃	.09	.08	.05	.12	.09	.13	.13	.09	.09
Volatile Matter	3.37	2.09	3.72	1.61	2.21	.66	.66	3.42	2.97

In general, it appears to be true despite the puzzling irregularities noted with respect to the insoluble and soluble silica that the silica as a whole seems to be in smaller quantity at California in any of the soils, and the soluble silica in greater quantity than at the other stations. In that respect therefore Hilgard's observations are confirmed. Just why, however, the smaller amount of leaching which should occur at Kansas than at Maryland should result in a higher insoluble silica content at Kansas is not clear to us and certainly is not capable of simple explanation.

POTASH.

The disturbance of the California soil at California causes a slight loss of potash, but its sojourn at Kansas or at Maryland is almost without effect in that respect, though possibly a slight loss occurs at Maryland when averages in all cases of the three-foot column are considered.

The Kansas soil loses very considerably in the average for the three-foot column by being placed either at California or at Maryland. The loss amounts to more than one-sixth of the total amount of acid soluble potash now in the Kansas soil at Kansas and is only slightly greater at Maryland than at California.

The Maryland soil like the Kansas soil loses potash in the average of the three-foot column by being placed either at California or at Kansas. The loss is, however, greater at California than at Kansas and amounts to more than one-fourth the acid soluble potash present now in the Maryland soil.

It may almost seem needless to remark that the losses in potash suffered by both the Kansas and the Maryland soils in California are difficult to account for, owing to the much smaller degree of leaching which occurs there than at other stations. In dealing with acid digestion of soils, however, it is possible that we introduce an error which may account for the differences between the potash content of the different soils which are above noted.

LIME AND MAGNESIA.

The California Soil.

The figures given above for lime and magnesia in the soils studied are as interesting as they are unexpected. For example, while the disturbance of the California soil as explained at its own location increases slightly the lime content, the increase is almost slight enough to be accidental; but when the same soil is maintained at Kansas as explained for seven years, it gains considerably in lime content in the first two feet. This is surprising since the superior conditions which we assume exist at Kansas for the promotion of leaching processes should give results opposite to those noted. When we consider the much more marked increase in lime which characterizes the same soil when placed at Maryland, we

are at a loss for a simple and ready explanation for the wholly unexpected fact.

The magnesia on the other hand is scarcely diminished in the California soil when the latter is allowed to remain at Kansas for seven years. At least this is so for the first two feet of soil in depth, while the third foot even receives an accretion of magnesia. When the same soil is placed at Maryland, however, the opposite effect of that noted in the case of the lime occurs, and the magnesia content particularly in the second and third foot of soil becomes much reduced in quantity.

Kansas Soil.

When the Kansas soil is placed at California it loses about 33 1/3 per cent of its lime in the first foot, but gains about as much in the second foot and nearly as much in the third foot. At Maryland we have again the unexpected and find a gain in the lime content of the Kansas soil of more than 25 per cent in the first foot, but a decided loss in both the second and third foot of the column.

With reference to magnesia the conditions are again different. The Kansas soil placed at California gains very slightly in the first foot, loses slightly in the second, and loses very decidedly in the third foot. When the same soil is placed at Maryland, however, an enormous increase in magnesia content in the soil occurs in seven years amounting to from three to five or more times the amount originally present in different parts of the soil column.

Maryland Soil.

Considering the relatively small amounts of both lime and magnesia which exist in the Maryland soil under its natural conditions it is interesting to note that it increases slightly in lime content when placed either at Kansas or at California. The increase is greatest at the latter place, and varies from .07 per cent to .08 per cent throughout the three-foot column. At Kansas the increase is found in the first and third foot, in which it amounts respectively to .06 per cent and .07 per cent, the original amount remaining stationary in the second foot.

With respect to its magnesia content, the Maryland soil shows much more evidence of change through its placement at Kansas and California (particularly the latter) than it does in the case of its lime content. Thus there is an increase in the magnesia content of the whole Maryland soil column at Kansas varying in magnitude from .02 per cent to .07 per cent. At California, however, while there is a possible slight loss of magnesia in the third foot of soil, there is a very large gain in the first and second foot of soil which amounts almost to a doubling of the original magnesia content.

MANGANESE.

The manganese content of the California soil when placed at Kansas and at Maryland becomes very markedly increased. Thus at Kansas it becomes approximately three times that contained in the same soil at its natural location, and the increase is similar throughout the whole soil column in the same soil in Maryland. Whether this striking difference, which of course cannot be attributed to accident, is of significance, remains to be determined and further discussed later.

In the Kansas soil, on the contrary, we start with a high manganese content and evidently reduce it rapidly by placing the soil either at California or at Maryland, particularly at the former. The manganese content of the Kansas soil at California in the first foot, for example, is only one-fourth that at Kansas, and at Maryland it is less than one-half that at Kansas.

The Maryland soil at its natural location contains less manganese than the California soil at its home position. Nevertheless, when it is placed at Kansas it gains for the three-foot column .07 per cent Mn_2O_3 , while at California it gains twice that amount in the same three-foot column. It appears now that even in this instance, in which the absolute quantities of manganese are small, the gains in that element experienced by the Maryland soil when placed for seven years at either California or at Kansas are above that of the experimental or accidental error, in magnitude.

IRON AND ALUMINA.

Some very interesting phases of the iron-alumina content of soils as affected by climate are suggested by the unusual data obtained by us as above reported. It appears in general that placing an eastern soil at California insures a large gain in iron and almost a correspondingly large loss in alumina and vice versa. The magnitude of these gains and losses may be equivalent to one-half to one-third the quantity originally present in the soil which is transplanted from its natural location to another, as exemplified in the procedure above outlined.

Taking for a little closer examination one soil at a time we find that the mere disturbance at its own location of the California soil while it is instrumental in altering the content of iron and alumina somewhat in the soil column does not markedly change the magnitude of the quantity of each of the substances in question in that soil. When, however, we keep the California soil at Kansas for seven years we find that it loses from one-third to one-half its iron content and at the same time gains correspondingly or nearly so in alumina content. In Maryland the soil does not suffer so great a loss in iron as it does at Kansas, yet it does lose large amounts thereof. On the other hand, its gain in alumina, especially in the second and third foot, is about equally large.

The Kansas soil nearly doubles in the three-foot column in iron content by being placed at California, but it loses correspondingly in alumina content. Hence the combined iron and alumina content is not very different in that respect in the Kansas soil at the two stations. Just as the California soil loses in iron and gains in alumina when placed at Maryland, so does the Kansas soil gain and lose conversely. It must be remarked, further, however, and this may be significant, that the losses and gains involved are of about the same order of magnitude in Maryland, whether the soil affected be the Kansas or the California soil. Moreover, in the absolute, the losses or gains are smaller than those involved in moving the California soil to Kansas or vice versa.

The Maryland soil remains unaffected or virtually so in respect to its iron content by being placed at Kansas. It loses decidedly, however, in respect to its alumina content. To be sure, it should be added that the quantity of iron in the Maryland soil is very small. When, however, the Maryland soil is placed at California its iron content is more than doubled and correspondingly its alumina content is decreased by more than 40 per cent.

PHOSPHORIC ACID

Though the difference is not very great in the absolute, it is quite clear from the table that the relative differences between the phosphoric acid content in the California soil at California on the one hand, and at Kansas and Maryland on the other, are very considerable. More specifically it appears that the tendency is for the California soil to increase in phosphoric acid content when placed either at Kansas or at Maryland. The increase is about the same at both places and amounts to from .02 per cent to .05 per cent.

When the Kansas soil is placed at California it is similarly affected to the California soil placed at Kansas except that the change occurs in the opposite direction. Thus a slight loss is suffered by the Kansas soil when it is placed at California. On the other hand, it remains unchanged at Maryland. In other words, the effects produced by moving the California soil and the Kansas soil to other stations seem to confirm each other.

The Maryland soil data are again irregular in that the decrease in phosphoric acid which seems to be characteristic of soils placed at California does not occur when the Maryland soil is so placed. It is even possible that the Maryland soil gains slightly in phosphoric acid by being placed at California. It must be added, however, that the phosphoric acid figures are practically the same, within the limits of error, when the whole three-foot column of soil is considered in every case.

SULPHURIC ACID.

The sulphuric acid data are indeed very irregular. Thus the California soil gains in sulphuric acid content when placed at Maryland but

loses in that respect when placed at Kansas. When, however, the Kansas soil is placed at California it too loses in sulphuric acid, but as in the case of the California soil gains in that respect in Maryland. The Maryland soil behaves in respect to sulphuric acid like the Kansas soil in that it loses in that constituent when placed at California. At Kansas, on the other hand, the Maryland soil gains in sulphuric acid.

In general, it now appears that the sulphuric acid data are of no great significance. Moreover, the figures as discussed above are gathered into totals for the soil columns of three feet and on such small absolute amounts may lead to error in comparison. We do not therefore attach very much weight to the data submitted under the heading "Sulphuric Acid."

HUMUS.

Since under humid conditions the humus of the first foot merely is of importance, the subsoil samples of these studies were not examined for humus and only the soil from the first foot of every column was studied. The Grandeau-Hilgard method for humus determination was employed. The following table indicates the percentages of humus found.

TABLE IX.
PERCENTAGE OF HUMUS (GRANDEAU-HILGARD METHOD).

Depth.	California Soil.			Kansas Soil.			Maryland Soil.		
	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.
1st Foot.....	1.00	1.06	1.28	1.05	1.15	.97	1.22	1.16	1.19

California soil "undisturbed" 1.02%

The variation in the percentage of humus in the different soils as shown in the foregoing table is not a great one and it is a matter of doubt if any significance may justifiably be attached thereto. Disregarding the latter point for a moment, however, it appears that the "disturbed" California soil had decreased in humus content over the check California soil, and that on the other hand the California soils both at Kansas and at Maryland had increased in humus content, the latter very appreciably, the former slightly. The Kansas soil, on the other hand, appears to have lost humus by its sojourn at both Maryland and California. While the loss at the latter station was to be expected on *a priori* grounds, the more marked loss at the former station is entirely unexpected. Another determination for humus on the same soil seemed only to confirm the earlier finding. As was true in other cases above discussed, the Maryland soil behaves irregularly with respect to the matter of its humus content. Thus it loses in humus content to the extent of .03 per cent by being placed at Kansas, but gains a similar amount at California.

TOTAL NITROGEN IN THE SOIL.

The total nitrogen determinations on the soils studied were carried out by the method above cited and the results are set forth in Table X which follows.

TABLE X.
PERCENTAGES OF TOTAL NITROGEN.

Depth.	California Soil.			Kansas Soil.			Maryland Soil.		
	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.
1st Foot. ....	.096	.092	.089	.128	.141	.120	.121	.110	.099
2nd Foot. ....	.081	.065	.071	.088	.095	.086	.065	.064	.057
3rd Foot. ....	.067	.064	.057	.065	.057	.070	.064	.063	.056

"Undisturbed" soil: 1st ft. .096; 2nd ft. .084; 3rd ft. .072

It is quite clear from a study of the data submitted in the foregoing table, that mere disturbance of the California soil at its own location is powerless to alter materially its nitrogen content, even for a depth of three feet. For example, the "disturbed" and "undisturbed" soil contain exactly the same amount of nitrogen in the first foot. In the second foot the disturbed soil contains .003 per cent less than the other, but the latter contains almost an equal amount less in the third foot, so that the two columns remain virtually alike in their nitrogen content.

When the California soil is placed at Kansas or at Maryland, however, a very appreciable change takes place in the direction of lowering the nitrogen content of the soil. This change is rather slight in the first and third foot of soil but much more marked in the second foot. Therefore when the whole three-foot column is considered the California soil loses considerable quantities of nitrogen under the climatic conditions which obtain either at Kansas or at Maryland in the short space of seven years. The loss for the three-foot column is appreciably greater in the case of the soil at Maryland than in that at Kansas.

The Kansas soil loses more nitrogen by being placed elsewhere than does the California soil when it is so treated. This is true for both the first and the second foot, but not for the third foot. The loss noted is greater in the case of the Kansas soil at Maryland than in that at California, but the difference, though distinct, is not great. In the third foot the Kansas soil gains both at California and at Maryland in nitrogen, the greater gain being at Maryland.

Unlike the other two soils, the Maryland soil gains in nitrogen by being placed either at Kansas or at California. This is true for the whole three-foot column. The gain is very considerably higher at California than at Kansas, but that is only true for the first foot, the other two being about alike in both cases. It is deserving of notice in the case of the Kansas and the Maryland soils that the percentage of nitrogen decreases

much more abruptly from the first to the second foot than it does in the case of the California soil.

In general, the data for the total nitrogen in the soils studied are not indicative of changes in any one direction wrought by climate as a determinant. For a given soil it appears that removal of an arid soil to more humid regions means a decided decrease in nitrogen. For another soil from another region the opposite may be true, or at different stations at two extremes of climate the effect may be in the same direction on a soil introduced into both. In other words, we appear again to be dealing in our nitrogen values (as submitted in the foregoing table) with algebraic sums of quantities of nitrogen, on the one hand added by nitrogen fixation of various kinds, and on the other hand of nitrogen losses of various kinds. It is of course clear that these two kinds of effects need not operate uniformly in all cases. Thus high nitrogen fixation may be offset by rapid nitrification followed by leaching, or denitrification, and the net gain be a very small one. Conversely, rapid loss of nitrogen by oxidation of organic nitrogen or destruction through vigorous action of cellulose destroying flora may be offset wholly or in part by nitrogen fixation. In view of the foregoing facts and observations, it appears impossible to make any general statement, whose validity may be unquestioned, as to the effect of climate on the nitrogen content of soils. It seems possible, however, to predict from known characteristics of a given soil and a knowledge of the conditions under which it is to be placed, whether it will decrease or increase in its nitrogen content.

REACTION OF THE SOILS.

The California and Kansas soils at all stations give a neutral or alkaline reaction to litmus paper. This is of course to be expected on the basis of the high calcium content of these soils. The Maryland soil, however, acts very differently and shows even by the litmus paper test some very marked changes due to climatic effects. For example, at its home station the Maryland soil shows a distinctly acid reaction in the surface foot and a decidedly acid reaction in the second and third feet. When placed at Kansas, however, the reaction of the first foot changes to a neutral one and that of the second and third feet still remains acid. At California, however, a further change occurs and the reaction of both the first and the second foot changes to neutral or slightly alkaline to litmus paper and remains acid only in the third foot.

WATER EXTRACT STUDIES.

In order to gain some insight into the situation with respect to the water soluble constituents of the soils here studied we prepared water extracts by the following method: Two hundred grams of soil were digested with 400 c.c. of distilled water for six days, during which time they were shaken up several times a day. At the end of the period named

the extracts were filtered, 50 c.c. portions representing 25 gm. of soil were evaporated in platinum dishes to dryness and brought to a constant weight at 100° C. The total residue was then weighed and the dishes ignited at a low red heat to dissipate the volatile matter. This made possible the determination of both the volatile and non-volatile fractions of the water extract. The non-volatile residue was then taken up in water, and detailed analyses will be made of these which are to be reported later. It suffices here merely to discuss the data given in Table XI which give the amounts in per cent of the volatile and non-volatile matter in the water extracts.

TABLE XI.
PER CENT WATER-SOLUBLE MATTER IN SOILS.

From Exchange Plot Experiment.

Series A—Total Volatile Matter.

Depth.	California Soil.			Kansas Soil.			Maryland Soil.		
	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.	In Cal.	In Kan.	In Md.
1st Foot.....	.0212	.0180	.0336	.0160	.0176	.0192	.0264	.0232	.0132
2nd Foot.....	.0168	.0236	.0388	.0180	.0348	.0184	.0196	.0332	.0128
3rd Foot.....	.0248	.0404	.0580	.0180	.0224	.0236	.0152	.0208	.0172

Series B—Total Inorganic Matter.

1st Foot.....	.0204	.0264	.0284	.0392	.0336	.0216	.0144	.0256	.0128
2nd Foot.....	.0120	.0232	.0292	.0204	.0372	.0148	.0268	.0240	.0108
3rd Foot.....	.0152	.0344	.0376	.0264	.0284	.0228	.0208	.0100	.0128

The results given in the foregoing table are very interesting and in our opinion of great significance in connection with the general question of concentration of the soil solution. Considering one soil at a time, it appears clear that the California soil increases enormously in water soluble matter both volatile and non-volatile by being placed under more humid conditions. Such increase may frequently be equivalent to nearly 100 per cent of the amount originally present. The gain in the respect noted is greater in all cases for the California soil at Maryland than at Kansas.

The Kansas soil when the soil column is considered, loses in water soluble volatile and non-volatile matter at California, and at Maryland.

The loss at California is in keeping with the climatic effects as brought out in the case of the California soil, but the loss at Maryland is diametrically the opposite of the expected result and remains to be explained when the more detailed analyses have been carried out.

The Maryland soil gains decidedly in water soluble matter at both Kansas and California. This fact seems to render nugatory any attempt to explain the existence of certain quantities of water soluble matter in soils on the basis of simple climatic effects, since the Maryland soil and its behavior negatives a possible conclusion from the California soil and its behavior. Thus the California soil gains in water soluble matter when moved to more humid climates, while the Maryland soil gains in the same

regard when placed under more arid climates.

While, therefore, no simple relationships can be discovered, and certainly no direct ones between climate and the amount of water soluble matter in soils, in the data we have above submitted and discussed, they are beyond cavil of great significance in other respects. In the first place, they lend further confirmation to the ideas expressed by other soil chemists that the concentration of the soil solution is not uniform for all soils, as has been claimed by some. In the second place, the figures clearly indicate that climate exerts a profound effect on the concentration of the soil solution even though such effect may be in opposite directions on two different soils. In the third place, our results show that volatile constituents of the soil water increase and decrease with the non-volatile portions, or vice versa. Lastly, it may be of significance that the quantities of the volatile and of the non-volatile matter, in the absolute, are very considerable and of about the same order of magnitude, in general.

COMPARISON OF OUR CHEMICAL DATA WITH THE PARTIAL DATA
OBTAINED BY SHAW AND WALTERS.

The following table is quoted from the bulletin by Shaw and Walters above referred to for the purpose of making a partial comparison of the chemical constitution of the soils here studied as they were five years ago and as they are to-day. It is obvious, as above indicated, that such comparisons must be taken *cum grano salis* since the methods employed in the analytical work were somewhat different, and the personal equation involved in the change in analysts cannot be overlooked.

TABLE XII.
PERCENTAGE COMPOSITION OF SOILS.

California Soil.

	Nitrogen.	Phosphoric acid.	Potash	Sulphuric acid.	Lime.	Magnesia.
1st Foot.....	.118	.161	.49	.121	.704	.703
2nd Foot.....	.074	.127	.473	.053	.621	1.69
3rd Foot.....	.058	.124	.462	.046	.683	1.48
Average .....	.083	.137	.475	.073	.669	1.29

Maryland Soil.

	Nitrogen.	Phosphoric acid.	Potash	Sulphuric acid.	Lime.	Magnesia.
1st Foot.....	.111	.114	.342	.13	.191	.42
2nd Foot.....	.076	.127	.278	.111	.222	4.75
3rd Foot.....	.042	.111	.450	.053	.204	4.72
Average .....	.076	.117	.357	.098	.205	3.927

Kansas Soil.

	Nitrogen.	Phosphoric acid.	Potash	Sulphuric acid.	Lime.	Magnesia.
1st Foot.....	.174	.160	.602	.14	.89	1.301
2nd Foot.....	.121	.173	.783	.08	.796	2.29
3rd Foot.....	.040	.165	.902	.09	1.69	2.18
Average .....	.111	.166	.762	.10	1.125	1.92

NOTE.—The "Official Methods" recorded in Bulletin No. 107 (revised) of the Bureau of Chemistry, U. S. Dept. of Agriculture, were followed in making the analyses recorded in this paper.

NITROGEN.

Beginning with the nitrogen consideration, it appears that the California soil has changed considerably even at its natural location with regard to its content of nitrogen. The change seems, however, to have been more in the nature of a redistribution of the nitrogen in the different soil layers than one of loss. This idea appears to receive support from the fact that the average nitrogen content of the three-foot column of the California soil is .083 per cent by the earlier analysis and is .081 per cent by our analysis. The redistribution of nitrogen referred to seems to have consisted in an increase of nitrogen in the second and third foot and a decrease in the first foot. At other points than at its natural location the California soil has in addition to the redistribution of its nitrogen suffered a loss of nitrogen as above explained.

The Kansas soil has suffered a loss of nitrogen equivalent to more than six times the loss suffered by the California soil, even if the average for the three-foot column is considered, and in addition has been subjected to a greater redistribution of nitrogen from the first foot into the subsoil. The average for the three-foot column by the earlier analysis is .111 per cent, while the average for the same column at its home location as found by us is .098 per cent. The loss suffered by the Maryland soil between the time of the Shaw and Walters' analysis and that of our analysis is midway between that of the California soil and that of the Kansas soil, if again the three-foot column of soil at its home station is considered. The averages for the two analyses in the order mentioned are .076 per cent and .071 per cent. The redistribution of nitrogen from the upper to the lower layers has also taken place in the Maryland soil as in the others.

In only two cases in the whole series of analyses do we note an increase in the average nitrogen content of the three-foot column, and they are both in the Maryland soil. One is in the case of the Maryland soil at California in which the average net gain for the three-foot column is .006 per cent and the other is in the case of the Maryland soil at Kansas in which the corresponding gain is .003 per cent.

PHOSPHORIC ACID.

With regard to phosphoric acid the California soil has altered but slightly at its own station for the three-foot column, but again as in the case of the nitrogen it has lost slightly in phosphoric acid content, and a redistribution has occurred which has rendered the surface foot considerably poorer than it was and the other two feet each somewhat richer in phosphoric acid than they were five years ago. By being moved to Kansas and to Maryland, however, and left there for the period stated, the California soil has increased in phosphoric acid content very considerably as above explained.

The Maryland soil at its home location has lost for the three-foot column about .014 per cent P_2O_5 , which is a very considerable amount. The loss has all been from the subsoil, since the surface foot has even gained .02 per cent P_2O_5 , thus showing the opposite tendency from the California soil. The Maryland soil at Kansas, however, has not lost any phosphoric acid during the five years and has even gained slightly, as has the California soil at both Kansas and Maryland. At California, however, the Maryland soil has lost very large quantities of phosphoric acid even when the whole three-foot column of soil is considered, the loss amounting as an average for the column to .044 per cent P_2O_5 .

The Kansas soil at its home location has lost .023 per cent P_2O_5 as an average of the three-foot column in five years, the loss having been greatest in the second foot, but appreciable in both the first and third feet as well. At California, however, the Kansas soil has lost even more phosphoric acid and it amounts to .053 per cent as an average for the three-foot column there. At Maryland the Kansas soil has also lost more heavily in phosphoric acid than at home, but not nearly as much as at California, the average loss for the column being .03 per cent.

POTASH.

The California soil has lost very slightly in its potash content in a period of five years when averages for the three-foot column are compared. There has, however, been a greater redistribution within the column itself in potash content. The changes occurring, if any, in respect to the potash content of the California soil at other stations are noted under the heading "Potash" above.

The Maryland soil has lost in the period noted .069 per cent K_2O as an average for the three-foot column at its home station and very much more at the other stations as explained above.

The Kansas soil, like the California soil, loses but slightly in potash content in five years when an average of the three-foot column at its home station is taken for comparison.

SULPHURIC ACID.

The data for the two analyses of the California soil at California indicate a decided gain in sulphuric acid during the past five years, and even a greater gain in that respect for the same soil placed at Maryland. At Kansas, however, the sulphuric acid content of the soil appears to remain about the same with perhaps a very slight loss.

The Maryland soil shows a very slight gain in sulphuric acid at its home location, but a more marked gain in that respect at Kansas. At California, however, a loss occurs which is more decided than the gain at Kansas.

The Kansas soil gains very decidedly at Kansas in sulphuric acid con-

tent for the average of the three-foot column. The gain occurs in both the second and third foot, while the first foot shows a loss. The gain in sulphuric acid at Maryland is appreciable, but not so great as at Kansas. Again the gain occurs in the subsoil and a loss is noted in the surface foot. At California a slight loss occurs in the three-foot column of the Kansas soil, the loss being in the first and third foot, a slight gain being noted in the second foot.

On the whole, it appears that accretions of sulphur have been received by most of the soil from some source outside of the three-foot column of soil studied, if the gain where occurring may not be explained on the basis of a change in the quantities of other constituents in a given weight of the soil.

LIME.

Most striking of all the changes noted in the soils in question as revealed by the two analyses carried out in 1910 and in 1915 respectively, are those pertaining to their lime and magnesia content. Considering the average lime content of the three-foot column, it appears that the California soil at California has lost about .05 per cent of lime, including total calcium of the soil. While such loss is appreciable, it can not be said to be great. The redistribution of the calcium in different layers of the soil however, has been more marked. Thus the surface foot of soil has lost .11 per cent calcium and the third foot has lost more than .07 per cent calcium while the second foot has gained nearly .10 per cent calcium.

In the case of the Kansas soil at Kansas we find a slight gain of CaO for the average of the three-foot column in five years amounting to about .06 per cent. Within the column we find a loss of .05 per cent in the first foot, a gain of .28 per cent in the second foot, and a gain of .03 per cent in the third foot.

The Maryland soil is not subject to such striking and inexplicable changes as the other soils, possibly because of its initially very low lime content. Nevertheless, at its home location it loses in the five year period mentioned nearly .05 per cent CaO for the average of the three-foot soil column. The loss occurs in the second and third foot of soil, the surface foot remaining almost stationary in CaO content, and perhaps even gaining slightly.

MAGNESIA.

The magnesia content of the soils here studied is subject to greater change, speaking generally, than the lime content in them, when analyses of 1910 and 1915 are compared. Thus the average percentage of magnesia in the California soil for the three-foot column in 1910 was 1.29, whereas now it has increased to 2.03 per cent. The increase occurs in the first and second foot only, the third remaining the same as before.

Most of the gain is in the second foot, however. The Kansas soil at its home location loses very heavily in magnesia (considerably more than half) as an average for the three-foot column in a period of five years. The loss is almost uniform throughout the three-foot depth of the soil. Considering now the Maryland soil it appears almost unbelievable to note the enormous losses in magnesia which that soil has suffered at its home location in five years. Starting with an average magnesia content of 2.30 per cent for the three-foot soil column, it now contains, after five years only .21 per cent, indicating a loss (occurring in all depths) amounting to over 90 per cent of the total quantity present.

GENERAL THEORETICAL AND OTHER CONSIDERATIONS.

Lack of space in this paper forbids an extended theoretical discussion of the causes underlying the effects above shown and discussed which result from climatic influences on soils. Some of the effects noted are easily explicable on the basis of present knowledge; others are but difficultly so, if at all capable of being explained in simple terms. Some features of the results obtained stand out quite clearly, however, despite their unexpected nature in some instances. For example, it appears that the total internal surface of soils per given unit of dry weight increases with a decrease in precipitation or with an increase in aridity. This must of course exercise, as in general it appears to do, an important influence on the hygroscopicity, moisture equivalent, wilting point, tenacity, absorptive power, and many other physical characteristics of a given soil. The reason for such increase in internal soil surface under an arid climate in a soil fairly supplied with organic matter can now be sought only in theory. It is reasonable for example to argue that under the stresses and strains incident to extremes of moisture conditions in the soil of an arid region there would be a greater tendency toward the formation of aggregates or compound particles than in the same soil placed under humid conditions. The lack of leaching in the arid region would permit of the accumulation of cementing materials which would also operate to the same end. All of this would only occur in the arid region in the presence of a fair supply of organic matter, since without the latter the particles of silt and sand would tend to become compacted and cemented into masses of relatively small internal surface. If this theoretical consideration is allowed, and it may be that we shall be able later to throw light on its validity or invalidity through specific gravity and other studies, then the general trend of the physical data above submitted can be accounted for. The exceptional manifestations, however, can not be explained in simple terms and we are obliged to defer a more detailed consideration of them to such time and place as are more propitious for that purpose than the present.

With regard to the chemical data obtained by us, the theoretical considerations on the causes underlying them are more difficult than in the case of the physical data. This is so because of the great irregularity of some of the results obtained and further because of the fact that data given in percentages for any one constituent on the basis of a complete analysis, depend for their nature so much on the relative proportions of the other constituents present. The result is that it is very difficult to determine if losses or gains shown by percentages are real or merely apparent losses or gains. Here again, as in the case of the physical data we shall undoubtedly be better able to connect the results obtained with the causes underlying them when we shall have obtained more data on both the real and apparent specific gravities of the soils here studied. While leaching and its effects are clearly factors in the rearrangement of percentages of the different constituents of the soil, it does not follow that the climate which permits of the greatest amount of leaching is one posite may indeed be true, and further light for such facts must be sought in the laws of physical chemistry governing complex systems of solutions. With these in mind, the reversal of conditions with respect to losses of lime and magnesia in the same soil under the same conditions or even of iron or alumina or other constituents, may become much more intelligible. With regard to the nitrogen fraction of the soil, sufficient has probably been said above for the elucidation of the results obtained. To discuss more specifically the theoretical phases of the chemical data obtained would require much more space than is allowed us here, and we are therefore obliged to defer such discussion for other papers. It suffices to remark here that the data submitted by us clearly indicate profound changes in the chemical constitution of a given soil when it is changed from an arid to a humid climate or vice versa, and that even under a given set of climatic conditions a period of five years may produce very profound chemical changes in a given soil. Obviously, such chemical changes are not independent of either the physical and biological changes which accompany them.

On the biological side, the theoretical considerations are not unlike those of the physical and chemical sides of the question of climatic effects on soils. In general bacterial activities are far more pronounced under humid than under arid conditions, and so far as the California and Kansas soils are concerned, there is but one exception to this tendency, and namely cellulose destruction, which proceeds with much greater activity in the arid than in the humid region. Bacterial numbers on the other hand offer another exception in the case of the Maryland soil which increases in numbers of bacteria when moved from humid to arid conditions. The general trend, however, which is noted is probably to be accounted for in the decrease in the carbon supply of soils under arid

conditions and by the decrease in the water soluble inorganic and organic matter as attested to by the data above submitted. These, in general would affect all the bacterial activities but would operate particularly to deprive the nitrogen fixing and nitrifying bacteria of their source of energy. The latter class of bacteria, moreover, would be affected in other ways by the difference in absorptive surface (as affected by organic matter) for the ammonia produced by the ammonifying flora and thus would be poisoned by an excess of free unabsorbed ammonia directly, or inactivated by the large amount of soluble organic matter produced in the soil by the ammonia. It is clear that this effect would be most marked in the case of the nitrification of blood nitrogen, since the blood is so readily dissolved by the ammonia, and hence poor results with nitrification would be obtained. The opposite would of course be true under arid conditions. This theory has been advanced elsewhere⁵ by the senior author to account for the non-nitrification of dried blood nitrogen in many arid soils when the blood is used in large quantities (1 per cent of the soil). In general, therefore, the theoretical conditions on the biological side of our problem seem to arrange themselves in a reasonable fashion tending toward the elucidation of the data obtained in the experiments.

Considering in conclusion the subject in the large, there can be no question that climate exerts in a very short space of time some very profound effects on a soil. It therefore appears questionable if after all, a tri-soil exchange plot experiment such as that which made our studies possible, gives for any length of time a true picture of what the same soil will do under three different climatic conditions. As we have seen, very deep seated changes in the soil occur with great rapidity when it is placed under a new set of climatic conditions. This would mean that wheat, for example, would not be grown on the same soil in three different localities, but on three different soils derived from one original soil under different climatic effects, and moreover that the differences would become more and more accentuated every year. It therefore seems, unjustifiable to assume that any differences in wheat grown under different climatic conditions on a soil supposedly the same in every climate, results merely from the climatic factor involved.

SUMMARY.

A considerable part of detailed studies on changes in the physical, chemical, and biological nature of soils occurring through climatic effects is discussed. The studies were carried out on soils from the soil exchange plots used for the study of the composition of wheat in a cooperative experiment established in 1908 by the Office of Cereal Investigations, United States Department of Agriculture, the Maryland Agricultural Ex-

periment Station, the Kansas Agricultural Experiment Station, and the California Agricultural Experiment Station. Among many striking facts revealed through these investigations only a few can be mentioned here. The reader must study the main discussions and tables to obtain a clear view of the results.

1. Soils change markedly in color in a period of seven years, and perhaps less, when moved to other climates. For example, Kansas and Maryland soils at California become more deeply reddish in color; California and Kansas soils become bleached to a light gray or yellowish gray at Maryland. The differences are so great that samples of any one original soil from the three different stations to-day show no outward resemblance among themselves, but appear to represent three very distinct soil types.

2. In general the hygroscopic coefficient, the moisture equivalent, and the wilting point of any of the soils increase when the soil is placed at California. Some exceptions to this rule are noted.

3. In general bacterial numbers increase in arid soils placed under humid conditions. In general, also the opposite is true for humid soils. The Maryland soil offers an exception to the latter rule.

4. Ammonification, nitrification and nitrogen fixation follow the general trend of bacterial counts as described in the last section. The general trend, however, applies in the case of nitrification to certain forms of nitrogen only. In the case of other forms of nitrogen very peculiar conditions exist which are fully explained above.

5. Cellulose destruction by soils proceeds with greater rapidity under arid than under humid conditions with any given soil type. Cellulose destruction therefore appears to follow in general the opposite course of other micro-organic activity in soils as affected by climate.

6. Marked changes in the acid soluble constituents of soils are wrought by climatic effects. It is difficult to generalize with respect to them, but it may be said that soils may often obtain accretions of the different constituents when removed from one climatic environment to another. Thus, for example, the California soil increases in lime at Kansas, and Maryland, particularly at the latter station, and loses in iron. The general tendency is for soils to increase in iron and decrease in alumina when placed under arid conditions, and vice versa.

7. Phenomenal losses in certain constituents in five years seem to have occurred in some soils even when the latter were not moved. Thus for example the Maryland soil loses in the period named enormous quantities of *magnesia*.

8. Very interesting data are submitted on the total water soluble constituents in the soils studied. Large increases occur in the California soil in that respect when it is moved to the Kansas or Maryland stations.

On the other hand, the Maryland soil gains in water soluble matter when moved to Kansas or to California.

The brief summary given above is merly fragmentary and, as explained above, the reader must seek a true picture of the variety and extent of the data obtained in the main body of the text.

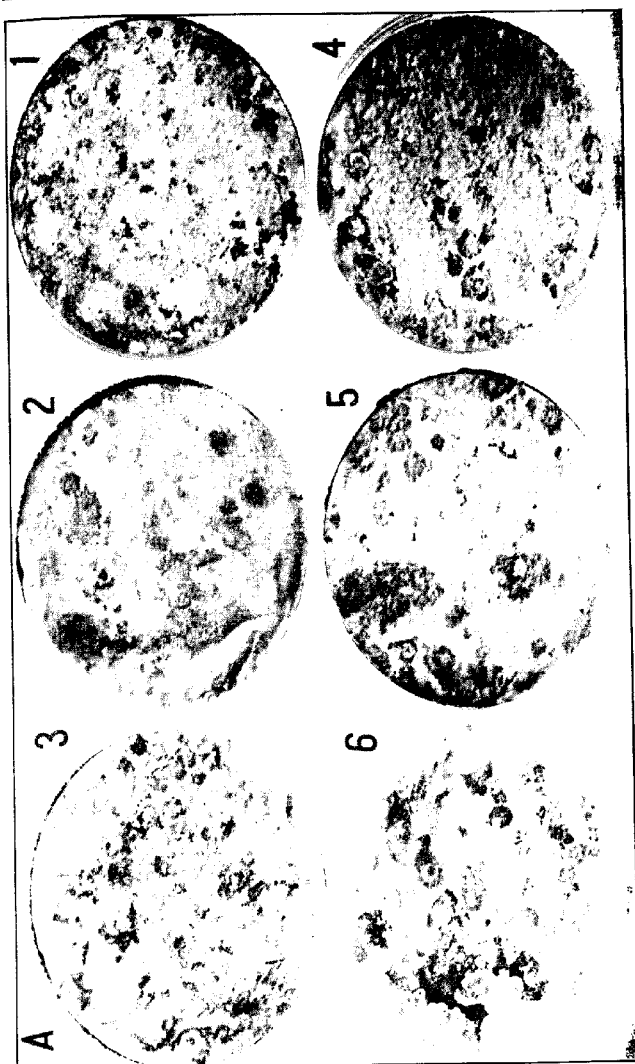
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PLATE I

Figs. 1, 2 and 3, show cellulose destruction by 1st, 2nd and 3rd foot of California soil (undisturbed) at California.

Figs. 4, 5 and 6—Same for same soil disturbed.



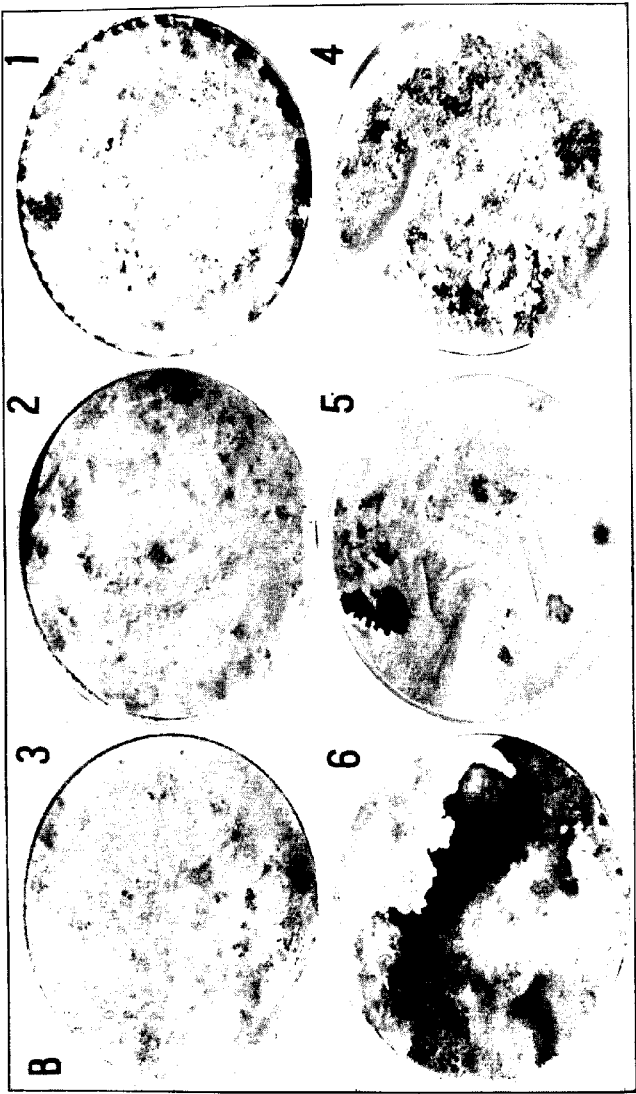


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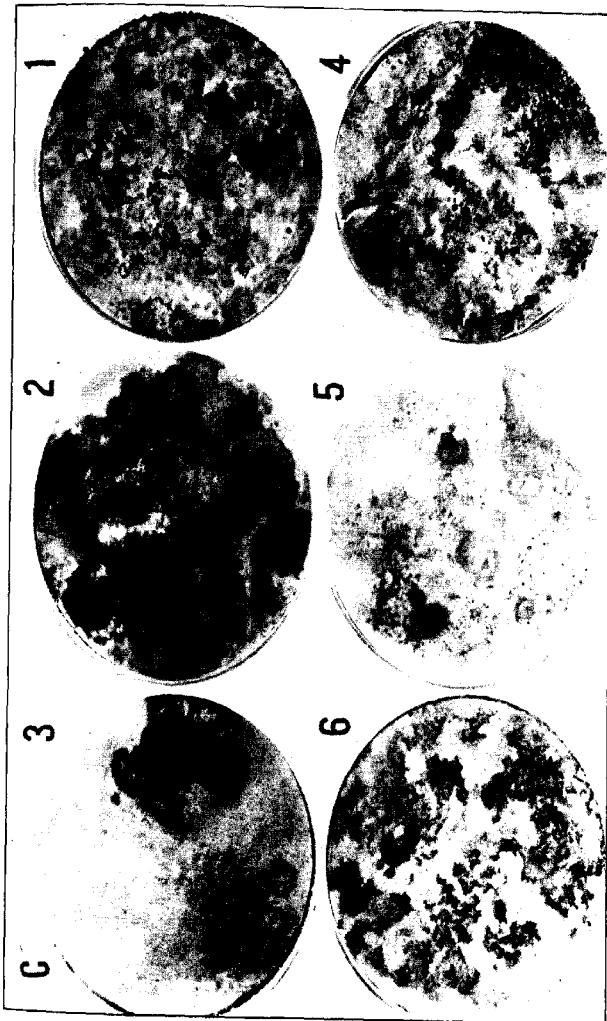
Figs. 1, 2 and 3, show cellulose destruction by 1st, 2nd and 3rd foot of California soil at Maryland.

Figs. 4, 5 and 6—Same for California soil as Kansas.

PLATE III

**Figs. 1, 2 and 3, show cellulose destruction by 1st, 2nd and 3rd foot of Kansas soil
at California.**

Figs. 4, 5 and 6—Same for Kansas soil at Kansas.



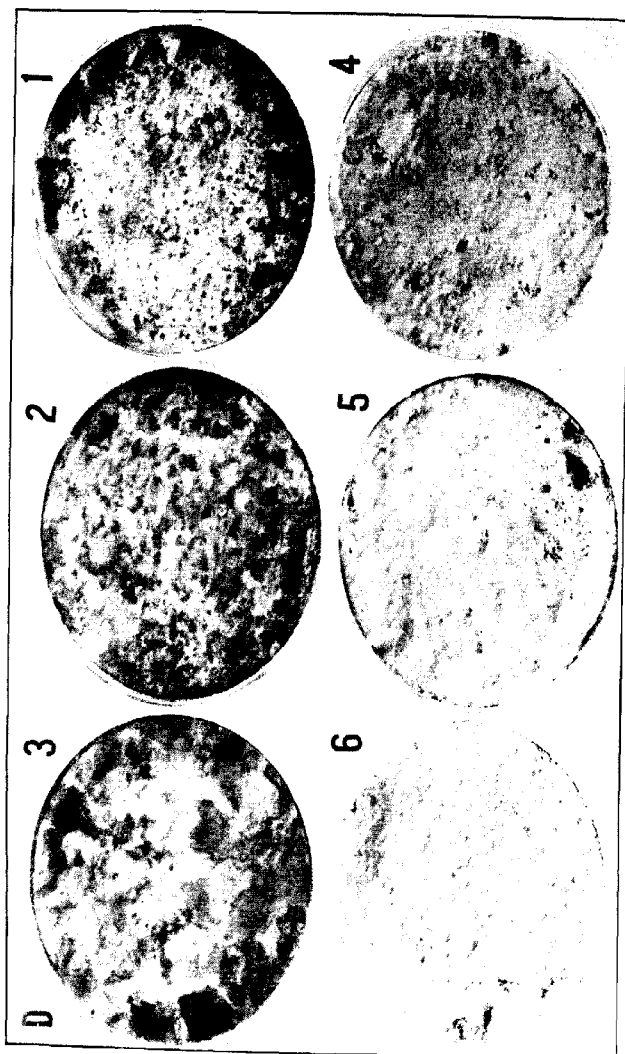


PLATE IV

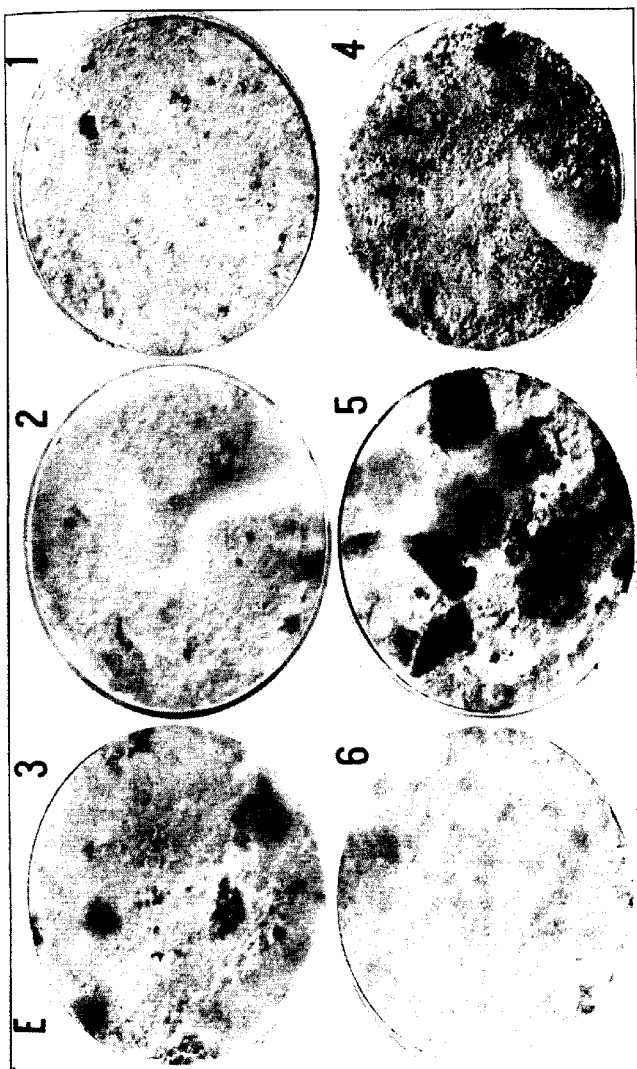
Figs. 1, 2 and 3, show cellulose destruction by 1st, 2nd and 3rd foot of Maryland soil at California.

Figs. 4, 5 and 6—Same for Kansas soil at Maryland.

PLATE V

Figs. 1, 2 and 3, show cellulose destruction by 1st, 2nd and 3rd foot of Maryland soil at Maryland.

Figs. 4, 5 and 6—Same for Maryland soil at Kansas.



THE INFLUENCE OF SOME COMMON HUMUS-FORMING MATERIALS OF NARROW AND OF WIDE NITROGEN-CARBON RATIO ON BACTERIAL ACTIVITIES.*

By P. E. BROWN AND F. E. ALLISON.

The determination of the nitrogen-carbon ratio in soils is now coming to be considered of much importance in fertility studies. Not only does it show the organic matter content of soils more accurately than the more or less arbitrary humus determinations concerning which considerable difference of opinion exists, but it also throws some light upon the rate at which decomposition processes are occurring in the soil.

When applications of organic matter are made to the soil, the nitrogen-carbon ratio of the soil is modified to a greater or less extent, depending on the ratio of these elements in the materials applied. Stewart⁴ has shown that the common humus-forming substances have a much wider ratio than soils, and hence the effect of turning under corn stover, oats straw or manure in a soil would be to widen the nitrogen-carbon ratio. The same author has also shown that under normal conditions the nitrogen-carbon ratio of the soil has a tendency to become narrower as the age of the organic matter increases. Other investigators have noted the same narrowing of the nitrogen-carbon ratio in decomposing organic matter and have concluded that it is due to the greater ease with which the carbonaceous portion of the organic matter is decomposed and disappears than is the case with the nitrogenous part.

Furthermore, as the more actively decomposable portions of the organic matter are removed, the remainder consists of rather inert materials whose decomposition proceeds, as would be expected, more slowly and with much more difficulty.

The presence, therefore, of a narrow nitrogen-carbon ratio in soils might be considered to show a deficiency in fresh organic matter and consequently a lack of the proper decomposition processes for the production of optimum amounts of available plant food.

This is actually the case in humid soils. Experience has shown that if the ratio narrows beyond a point of about 1 to 10, crop yields may be reduced, evidently because of an insufficient production of available nitrogen, phosphorus and potassium. On the other hand, if the ratio is 10 to 12 or above, bacterial activities apparently occur to a satisfactory extent and sufficient amounts of soluble plant food are produced for good crop growth.

The question now arises whether, when a soil shows a narrow nitrogen-carbon ratio and hence a lack of fresh organic matter, materials of

* From the Soil Chemistry and Bacteriology Laboratory, Iowa State College.

the widest possible ratio should be chosen to supply the deficiency. In other words, would the bacterial activities and crop yields be benefitted to as great an extent by additions of straw as by the turning under of a crop like clover which has a much narrower nitrogen-carbon ratio, but at the same time supplies more nitrogen to the soil?

It is commonly believed that clovers or other leguminous green manure crops are of much more value for supplying deficiencies of organic matter in soils than straws or stover, but the latter materials may be applied at a much less expense and if they will serve as well, that is if they will have the same or a better effect on bacterial activities and crop yields, they should be used.

Obviously, the nitrogen content of the soil should be considered in making a choice of materials to increase the organic matter content. When nitrogen is lacking, should leguminous crops be employed because of the nitrogen which they supply? Would it not be quite as satisfactory to increase the organic matter content of the soil and the decomposition processes by the use of a cheaper material which would increase the fixation of nitrogen from the atmosphere? Would these cheaper materials exert a sufficiently greater effect on bacterial activities especially on azo-fication or non-symbiotic nitrogen-fixation to prove as valuable as the leguminous green manures?

In other words, with the straws, would a sufficiently large increase in nitrogen content in the soil occur through azo-fication to keep the crop as well supplied with nitrogen as when the legumes were used? Again, would the nitrogen present in the soil be made available as fast by the decomposition produced by the straws as that present in the legumes is transformed by the decomposition which they engender?

These are the questions which arose from a consideration of the question of the nitrogen-carbon ratio in soils and which the experiments reported in the following pages were planned to answer.

Briefly then, it may be said that the purpose of this work was to study the influence of materials of narrow and of wide nitrogen-carbon ratio, when applied to soils low in organic matter, on certain bacterial activities. The processes studied were those which are important from the standpoint of the decomposition of nitrogenous organic matter, namely ammonification and nitrification, and that which concerns the increase in soil nitrogen, namely azo-fication or non-symbiotic nitrogen-fixation.

The comparative effects of these materials on the growth of oats in greenhouse pots were also studied in the attempt to ascertain whether the crop yields were affected in a manner similar to the bacterial processes and also to determine if possible, whether inexpensive materials of a narrow nitrogen-carbon ratio would not, upon undergoing decay, stimulate bacterial activities and especially increase sufficiently the fixation by the soil of nitrogen from the atmosphere, to give as satisfac-

tory yields as materials containing more nitrogen in proportion to the carbon present.

THE PLAN OF THE EXPERIMENT.

The soil chosen for this work was secured from one of the college experimental orchards and is classed by the Bureau of Soils as Miami sandy loam. It was low in organic matter and slightly acid in reaction showing a lime requirement, according to the Veitch method, of 736 pounds of calcium carbonate per acre of two million pounds of surface soil. Before the special treatments were made, therefore, sufficient calcium carbonate was applied to neutralize the acidity and bring the lime content of the soil up to two tons per acre.

After being sieved, air-dried and treated with lime as mentioned, the soil was filled into thirty-six earthenware pots in the greenhouse, at the rate of 36 pounds to the pot.

The special treatments of the pots were as follows:

- 1- 2—Check.
- 3- 4—15 tons horse manure per acre.
- 5- 6—15 tons cow manure per acre.
- 7- 8—15 tons rotted manure per acre.
- 9-10—2½ tons oat straw per acre.
- 11-12— 3 tons corn stover per acre.
- 13-14— 2 tons timothy hay per acre.
- 15-16— 4 tons cowpea hay per acre.
- 17-18— 4 tons clover hay per acre.
- 19-20—Check.
- 21-22—15 tons horse manure per acre.
- 23-24—15 tons cow manure per acre.
- 25-26—15 tons rotted manure per acre.
- 27-28—2½ tons oat straw per acre.
- 29-30— 3 tons corn stover per acre.
- 31-32— 2 tons timothy hay per acre.
- 33-34— 4 tons cowpea hay per acre.
- 35-36— 4 tons clover hay per acre.

Pots 19 to 36 were seeded to oats and the others were kept bare to allow the taking of samples for bacteriological tests.

The rate of application of the materials used was based on farm conditions, approximately the same amounts being applied as if a maximum crop were grown and turned under in the soil or a heavy application of manure was made.

All of the materials were dried and ground before being applied, but the application of the manures was calculated on the wet basis while in all the other cases the dry basis was used. All applications were figured on the basis of two million pounds of soil per acre.

After mixing the various materials thoroughly with the soil, the oats were seeded in the proper pots and all received 100 c.c. of an infusion made by shaking for five minutes, fresh soil with water in the proportion of 100 gm. per 200 c.c. of water. This was to supply a vigorous bacterial flora from the soil in its natural state in order that the decomposition of the various materials might proceed as rapidly as it would in the field.

The optimum moisture content of the soil was determined and after the addition of the infusions sufficient additional water was supplied to bring the water content in each pot up to the optimum. The pots were then weighed and additions of water were made at regular intervals during the continuance of the experiment to maintain a constant weight.

The oats were harvested just prior to maturity and were dried, ground and analyzed.

Samples were drawn for bacteriological tests once every two or three weeks and the ammonifying, nitrifying, and azofying or nitrogen-fixing powers of the soils were determined.

The casein-fresh-soil method¹ and the dried blood-fresh-soil method were used for ammonification. The ammonium-sulfate-fresh soil method served for nitrification and the mannite-fresh-soil and dextrose-fresh-soil methods were employed for azofication.²

The samples for the bacteriological tests were drawn with the usual precautions to avoid contamination and thorough mixing was insured before the one-hundred-gram portions were weighed out for the various tests. The moisture content of all the soils was determined at each sampling and the moisture content of the soils in all the tests was adjusted to two-thirds of the saturation point.

In the nitrification tests the moisture content of the samples was kept up by additions of sterile water to weight every ten days.

The incubation took place at room temperature which was fairly constant at 23-25° C. The incubation period varied as will be noted in the later discussions.

The ammonification determinations were made in all cases except one by the magnesium-oxide method. In one instance the aeration method of Potter and Snyder³ was used.

The nitrate determinations were made by the phenol-disulfonic acid method and total nitrogen was estimated by the regular Kjeldahl method.

THE EFFECT OF THE MATERIALS ADDED ON THE NITROGEN-CARBON RATIO IN THE SOIL.

The nitrogen and the carbon content of the soil and of all the materials used were determined and the nitrogen-carbon ratio calculated. These results are given in Table I.

TABLE I.
NITROGEN AND CARBON IN SOIL AND IN MATERIALS USED.

Materials Analyzed.	Nitrogen Per Cent.	Carbon Per Cent.	Nitrogen-Carbon Ratio.
Soil	0.0988	1.3481	1 : 13.644
Horse manure	1.6468	38.7614	1 : 23.537
Cow manure	2.4176	36.6160	1 : 15.145
Rotted manure	2.4461	23.9047	1 : 9.772
Oat straw .....	.8390	38.1622	1 : 44.426
Corn stover	1.4762	39.8266	1 : 26.979
Timothy hay .....	.9727	38.1502	1 : 39.221
Cowpea hay	2.1852	42.1834	1 : 19.304
Clover hay	2.0564	41.3085	1 : 20.088

The soil used showed a satisfactorily wide ratio and hence the effects of the materials added cannot be expected to appear as definitely as might be the case did the soil itself contain a smaller amount of organic matter of a narrower ratio.

The rotted manure had the narrowest ratio of any of the materials employed and the oat straw the widest. The cow manure had a narrower ratio than the horse manure and the relative amounts of nitrogen and carbon in the legume hays were about the same as those in the horse manure.

In Table II are given the results showing the amounts of nitrogen and carbon added to the soils in the various materials applied and the nitrogen-carbon ratio in the soils after the applications were made.

It will be seen that all the materials applied brought about a widening of the nitrogen-carbon ratio except the rotted manure which narrowed the ratio. This is in accord with the results in the previous table which showed that the rotted manure had a narrower ratio than the soil itself and hence it might be expected to narrow the ratio in the soil. The oat straw widened the ratio more than any of the hays, particularly the legumes.

The horse manure brought about a greater widening of the ratio than the other materials applied, greater even than those which had a wider ratio than the horse manure. This is evidently due to the very much larger application of the horse manure than of the straw, stover and hays.

It will be recalled that the amounts of all the materials used were calculated as maximum field applications and hence it is interesting to note the relative influence of the different substances and to consider them from the field standpoint.

TABLE II.
NITROGEN-CARBON RATIO IN SOILS AFTER TREATMENT.

Pot No.	Treatment.	Materials added gm.	N added gm.	C added gm.	Total N gm.	Total C gm.	N-C Ratio.
1	Check	none	none	none	16.14	220.26	1 : 13.6
2	Check	none	none	none	16.14	220.26	1 : 13.6
3	Horse manure	78.19	1.29	30.31	17.43	250.57	1 : 14.4
4	Horse manure	78.19	1.29	30.31	17.43	250.57	1 : 14.4
5	Cow manure	59.63	1.44	21.84	17.59	242.10	1 : 13.8
6	Cow manure	59.63	1.44	21.84	17.59	242.10	1 : 13.8
7	Rotted manure	83.65	2.05	20.00	18.19	240.26	1 : 13.2
8	Rotted manure	83.65	2.05	20.00	18.19	240.26	1 : 13.2
9	Oat straw . .	40.85	0.35	15.59	16.50	235.85	1 : 14.3
10	Oat straw . .	40.85	0.35	15.59	16.50	235.85	1 : 14.3
11	Corn stover .	49.02	0.72	19.52	16.87	239.79	1 : 14.2
12	Corn stover .	49.02	0.72	19.52	16.87	239.79	1 : 14.2
13	Timothy hay	32.68	0.32	12.47	16.46	232.73	1 : 14.1
14	Timothy hay	32.68	0.32	12.47	16.46	232.73	1 : 14.1
15	Cowpea hay .	65.36	1.43	27.57	17.57	247.83	1 : 14.1
16	Cowpea hay .	65.36	1.43	27.57	17.57	247.83	1 : 14.1
17	Clover hay . .	65.36	1.34	27.00	17.49	247.26	1 : 14.1
18	Clover hay . .	65.36	1.34	27.00	17.49	247.26	1 : 14.1

Rotted manure actually narrowed the ratio and hence might be considered as having the least effect on the decomposition processes, while

all the other materials increased the proportion of carbon to nitrogen and hence should increase bacterial activities to a much greater extent.

Among the straws and hays used, with the exception of timothy hay, the wider the nitrogen-carbon ratio, the greater the widening of the ratio in the soil when they were applied. It might be expected, therefore, that the materials of the wider ratios would give greater effects on bacterial processes than those whose content in nitrogen and carbon was more nearly the same.

The changes in the nitrogen-carbon ratio in this soil, by the applications of these materials were very much smaller, undoubtedly, than would have occurred if a soil of a narrower ratio had been chosen.

It is apparent, however, that the ordinary humus-forming materials on the farm, when applied to the soil, widen the nitrogen-carbon ratio of the soil even when it is not extremely narrow and hence should be expected to increase bacterial activities to a beneficial extent, and consequently increase decomposition processes and the production of available plant food, and increase also the fixation of nitrogen from the atmosphere.

THE AMMONIFICATION EXPERIMENTS.

The experiment was started on December 5th and the first sampling was made on December 24th, in order to allow time for decomposition to commence. Samplings were made approximately every two weeks, the dates being January 7, January 28, February 12, February 26 and March 12.

The results of the ammonification tests in which casein was used and those secured with dried blood are considered separately, but general conclusions will be drawn from both lots of experiments. The incubation period in the case of casein was three and four days, while with the dried blood it was six and seven days.

THE AMMONIFICATION OF CASEIN.

The results in a summarized form, of the ammonification experiments with casein are given in Table III and in Table IV. Where individual results were widely at variance with the general trend of the results as shown throughout the six samplings, they were omitted from the averages. The tests at the first three samplings were incubated four days and those on the remaining dates were incubated three days.

Very much larger amounts of ammonia were produced in the samples taken on January 7, than in the tests at the other dates. This is probably due to an increase in room temperature to 29° C. which occurred while the samples were being incubated.

It will be seen in Table III that for the most part the duplicate determinations agreed very satisfactorily, or at least much better than in the case of other tests with different nitrogenous materials.

TABLE III.
THE AMMONIFICATION OF CASEIN.

Pot No.	Lab. No.	I. December 24.		II. January 7.		III. January 28.	
		Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.
1	1	82.32	.....	100.94	.....	85.63	.....
..	2	92.47	87.54	104.72	102.84	89.29*	85.63
2	3	87.06	.....	101.85	.....	83.67	.....
..	4	90.97	89.01	103.40	102.62	89.15*	83.67
3	5	90.29	.....	105.57	.....	92.05	.....
..	6	90.97	90.63	104.72	105.14	94.22	93.13
4	7	89.76	.....	103.83	.....	90.28	.....
..	8	84.05*	89.76	104.49	104.16	86.61	88.45
5	9	86.08*	.....	105.57	.....	86.19	.....
..	10	89.01	89.01	108.68	107.12	89.99	88.09
11	11	88.41	.....	104.72	.....	81.83*	.....
..	12	89.99	89.24	104.49	104.60	85.73	85.73
7	13	88.49	.....	103.83	.....	90.17	.....
..	14	89.01	88.75	105.81	104.82	87.31	88.74
8	15	89.01	.....	102.93	.....	85.63	.....
..	16	90.97	89.99	109.11	106.02	84.50	85.06
9	17	86.53	.....	106.04	.....	85.63	.....
..	18	90.97	88.75	105.38	105.71	83.38	84.50
10	19	86.51	.....	98.79	.....	81.96	.....
..	20	90.29	88.90	100.76	99.77	83.67	82.81
11	21	89.01	.....	102.51	.....	82.25	.....
..	22	90.97	89.99	100.76	101.63	88.87	85.56
12	23	89.76	.....	105.10	.....	84.80	.....
..	24	90.97	90.36	102.51	103.80	89.43	87.12
13	25	92.17	.....	102.32	.....	86.61	.....
..	26	88.14	90.25	105.10	103.71	82.53	84.52
14	27	89.54	.....	104.25	.....	84.38	.....
..	28	88.49	89.01	97.70	100.97	78.73	82.55
15	29	85.55	.....	105.10	.....	78.59	.....
..	30	85.55	85.55	99.21	102.25	78.55	78.57
16	31	89.54	.....	105.51	.....	78.59	.....
..	32	89.54	89.54	107.83	106.67	80.14	79.36*
17	33	90.97	.....	108.03	.....	86.33	.....
..	34	89.99	90.48	106.23	107.13	87.18	86.75
18	35	90.97	.....	105.57	.....	86.47	.....
..	36	87.06	89.01	107.13	106.35	81.83*	86.47

Pot No.	Lab. No.	IV. February 12.		V. February 26.		VI. March 12.	
		Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.
1	1	84.38	.....	88.69	.....	92.39	.....
..	2	86.15	85.26	90.47	89.58	94.42	93.40
2	3	83.66	.....	88.58	.....	91.44	.....
..	4	85.99	84.82	90.37	89.47	94.69	93.05
3	5	87.04	.....	92.75	.....	96.31	.....
..	6	85.99	86.51	92.16	92.45	95.50	95.90
4	7	89.89	.....	92.75	.....	98.48	.....
..	8	85.27	87.58	lost	92.75	94.42	96.45
5	9	84.91	.....	96.03	.....	98.88	.....
..	10	87.24	86.07	93.38	94.70	93.88	96.38
6	11	85.09	.....	92.75	.....	98.34	.....
..	12	85.27	85.18	92.75	92.75	94.42	96.38
7	13	85.09	.....	91.26	.....	94.01	.....
..	14	86.87	85.98	92.75	92.00	86.02*	94.01
8	15	86.51	.....	92.45	.....	94.28	.....
..	16	87.60	87.05	93.05	92.75	93.34	93.81
9	17	85.79	.....	91.86	.....	93.74	.....
..	18	82.41	84.10	93.38	92.62	94.55	94.14
10	19	82.60	.....	92.45	.....	92.25	.....
..	20	82.60	82.60	94.54	93.49	88.59	90.42
11	21	87.42	.....	87.98	.....	92.93	.....
..	22	85.09	86.25	90.47	89.22	94.55	93.74
12	23	83.49	.....	88.47	.....	92.79	.....
..	24	86.71	85.10	90.67	89.57	88.32*	92.79
13	25	86.87	.....	89.18	.....	90.90	.....
..	26	84.02	85.44	88.58	88.88	89.81	90.35
14	27	86.71	.....	92.45	.....	93.20	.....
..	28	84.54	85.62	92.15	92.30	89.27	91.23
15	29	85.27	.....	91.56	.....	91.72	.....
..	30	84.45	84.81	88.47	90.01	96.04	93.88
16	31	85.99	.....	91.26	.....	87.78	.....
..	32	88.29	87.14	lost	91.26	91.44	89.61
17	33	87.76	.....	91.26	.....	93.61	.....
..	34	87.60	87.68	88.58	89.92	91.57	92.59
18	35	87.60	.....	88.58	.....	93.88	.....
..	36	85.99	85.78	88.47	88.52	92.52	93.20

*Results omitted from the averages.

The differences in ammonifying power between the different soils were not, however, very large, and it is very difficult in such cases to draw definite conclusions.

TABLE IV.
THE AMMONIFICATION OF CASEIN.

Pot No.	Treatment.	I.		II.		III.	
		Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.
1	Check	87.54	.....	102.84	.....	85.63	.....
2	Check	89.01	88.27	102.62	102.73	83.67	84.65
3	Horse manure	90.63	.....	105.14	.....	93.13	.....
4	Horse manure	89.76	90.19	104.16	104.65	88.45	90.79
5	Cow manure	89.01	.....	107.12	.....	88.09	.....
6	Cow manure	89.24	88.39	104.60	105.86	85.73	86.91
7	Rotted manure	88.75	.....	104.82	.....	88.74	.....
8	Rotted manure	89.99	89.37	106.02	105.42	85.06	86.90
9	Oat straw	88.75	.....	105.71	.....	84.50	.....
10	Oat straw	88.90	88.82	99.77	102.74	82.81	83.65
11	Corn stover	89.99	.....	101.63	.....	85.56	.....
12	Corn stover	90.36	90.17	103.80	102.71	87.12	86.34
13	Timothy hay	90.25	.....	103.71	.....	84.52	.....
14	Timothy hay	89.01	89.63	100.97	102.34	82.55	83.53
15	Cowpea hay	85.55	.....	102.25	.....	78.57	.....
16	Cowpea hay	89.54	87.54	106.67	104.46	79.36	78.96
17	Clover hay	90.48	.....	107.13	.....	86.75	.....
18	Clover hay	89.01	89.74	106.35	106.74	86.47	86.61

Pot No.	Treatment.	IV.		V.		VI.	
		Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.
1	Check	85.26	.....	89.58	.....	93.40	.....
2	Check	84.82	85.04	89.47	89.52	93.05	93.22
3	Horse manure	86.51	.....	92.45	.....	95.90	.....
4	Horse manure	87.58	86.54	92.75	92.60	96.45	96.17
5	Cow manure	86.07	.....	94.70	.....	96.38	.....
6	Cow manure	85.18	85.62	92.75	93.72	96.38	96.38
7	Rotted manure	85.98	.....	92.00	.....	94.01	.....
8	Rotted manure	87.05	86.56	92.75	92.35	92.79	93.91
9	Oat straw	84.10	.....	92.62	.....	94.14	.....
10	Oat straw	82.60	83.35	93.49	93.05	90.42	92.28
11	Corn stover	86.25	.....	89.22	.....	93.74	.....
12	Corn stover	85.10	85.67	89.57	89.38	92.79	93.26
13	Timothy hay	85.44	.....	88.88	.....	90.35	.....
14	Timothy hay	85.62	85.53	92.30	90.59	91.23	90.79
15	Cowpea hay	84.81	.....	90.01	.....	93.88	.....
16	Cowpea hay	87.14	85.97	91.26	90.63	89.61	91.74
17	Clover hay	87.68	.....	89.92	.....	92.59	.....
18	Clover hay	85.78	86.73	88.52	89.22	93.20	92.89

In general, however, considering the results as a whole, it appears from Table IV that horse manure, cow manure, and rotted manure favored the ammonifying bacteria to the greatest extent. Next in order came clover hay, corn stover, oat straw, cowpea hay and timothy hay, respectively. In the case of the latter materials the differences were not large, and their relative effects varied greatly at the different samplings.

For the most part, however, all the materials increased the ammonifying power of the soil, according to the tests and while in a few instances some depressing action was noted, the figures were not widely enough separated for the results to be conclusive.

Some depression in the ammonifying power of soils may occur immediately following the application of materials similar to those used in these experiments, but after such substances commence to decompose,

any decrease in the activities of the ammonifying bacteria would hardly be expected. Some decomposition of all the materials used in this work had undoubtedly occurred prior to the making of any tests and hence it seems probable that the slight depressions noted should be considered merely as indications of the absence of any particular increasing action of the substances applied. The variations from the results with the check soils should in such a case be considered as due to experimental error or accidental contamination. Much more distinctive results than those secured here must be obtained before the occurrence of any depressing action could be considered as the rule with the use of these materials.

In short, it seems safe to conclude that applications of humus-forming materials increased the ammonifying power of soils as indicated by tests with the casein-fresh-soil method. The manures had a greater effect than straw, stover or hays; and horse manure and cow manure showed much more influence than rotted manure. It must be recalled here that the bacterial factor was the same in all the pots, as the materials were all added in a dry condition and different effects were due, therefore, to differences in amounts added or in composition.

While the casein-fresh-soil method gives very satisfactory results from the standpoint of agreement of duplicates and because of ease of manipulation, it is apparent that some further modification will be necessary to make it possible for distinctive results to be secured with its use. The dried-blood-fresh-soil method although much more difficult to use is evidently better suited for general soil studies and causes a wider difference to be shown in ammonifying power between soils differently treated.

Reference will again be made to the results with casein after the dried-blood experiments are considered.

THE AMMONIFICATION OF DRIED BLOOD.

The samples drawn on the same dates as previously mentioned when the ammonifying power of the soils was tested with casein, were used for ammonification tests with dried blood, except that no tests were made on January 7. An additional sampling was made, however, on March 24, so that six series of results were secured here. Thus there was provided a comparison of the two methods as well as additional data on the ammonifying power of the soils.

The results of the tests with dried blood are given in Table V and the summarized results appear in Table VI.

The incubation period for the first, third and fifth sampling was seven days; for the fourth and sixth it was six days and in the second series one-half of the determinations were made on the fifth day and the duplicate half on the sixth day. This second series was distilled by the aera-

TABLE V.
THE AMMONIFICATION OF DRIED BLOOD.

Pot No.	Lab. No.	I. December 24.		II. January 28.		III. February 12.	
		Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.
1	1	75.31	.....	29.09	.....	lost	.....
2	2	78.83	77.07	67.71*	29.09	lost	.....
3	3	87.05	.....	25.90	.....	lost	.....
4	4	59.47	73.28	32.22	29.06	42.15	42.15
5	5	92.63	.....	25.11*	.....	lost	.....
6	6	96.24	94.43	50.95	50.95	62.52	62.52
7	7	102.90	.....	37.70	.....	lost	.....
8	8	85.26	94.58	lost	37.70	78.36	78.36
9	9	116.58	.....	33.55	.....	lost	.....
10	10	97.00	106.79	lost	33.55	52.34	52.34
11	11	93.12	.....	47.08	.....	lost	.....
12	12	70.43	81.77	72.31	59.69	75.53	75.53
13	13	93.44	.....	44.71	.....	lost	.....
14	14	129.67	111.55	57.22	50.96	90.81	90.81
15	15	119.91	.....	39.13	.....	lost	.....
16	16	102.12	106.51	73.13	56.13	73.21	73.21
17	17	78.63	.....	44.04	.....	lost	.....
18	18	89.57	84.10	60.28	52.16	97.60	97.60
19	19	87.04	.....	43.70	.....	lost	.....
20	20	84.16	85.60	40.32	42.01	51.20	51.20
21	21	83.91	.....	48.10	.....	lost	.....
22	22	87.25	85.58	55.53	51.81	43.85	43.85
23	23	83.57	.....	43.01	.....	lost	.....
24	24	84.29	83.43	59.26	51.13	68.74	68.74
25	25	112.09	.....	52.85	.....	lost	.....
26	26	76.43	94.36	75.39	64.12	63.65	63.65
27	27	102.71	.....	46.41	.....	lost	.....
28	28	107.40	105.05	73.43	59.92	67.05	67.05
29	29	88.60	.....	33.91	.....	lost	.....
30	30	61.43	75.01	53.84	43.87	61.39	61.39
31	31	85.68	.....	42.01	.....	lost	.....
32	32	84.81	85.24	72.91	57.46	51.77	51.77
33	33	83.90	.....	51.16	.....	lost	.....
34	34	78.84	81.37	50.14	50.65	57.43	57.43
35	35	92.53	.....	40.00	.....	lost	.....
36	36	81.75	87.14	62.29	51.14	107.22*	.....

Pot No.	Lab. No.	IV. February 26.		V. March 12.		VI. March 24.	
		Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.
1	1	95.33*	.....	52.57	.....	57.73	.....
2	2	89.07*	.....	41.98	47.27	92.56*	57.73
3	3	46.88	.....	43.87	.....	67.71	.....
4	4	51.86	49.37	43.60	43.73	93.54*	67.71
5	5	58.31	.....	57.19	.....	91.17	.....
6	6	91.71	75.01	73.71	65.45	93.74	92.45
7	7	81.45	.....	76.62	.....	87.67	.....
8	8	81.16	81.30	97.96	87.29	113.09	100.38
9	9	101.38	.....	76.62	.....	68.93	.....
10	10	89.37	95.36	71.18	73.90	83.95	76.44
11	11	101.67	.....	92.38	.....	46.77*	.....
12	12	108.12	104.89	74.58	83.48	100.39	100.39
13	13	96.98	.....	46.72	.....	70.65	.....
14	14	109.88	103.43	54.75	50.73	88.65	79.65
15	15	105.48	.....	95.92	.....	111.74	.....
16	16	119.25	112.36	73.90	84.91	88.04	99.89
17	17	62.70	.....	63.03	.....	53.39	.....
18	18	55.67	59.18	58.14	60.58	76.52	64.95
19	19	78.23	.....	55.15	.....	81.60	.....
20	20	87.31	82.77	94.97	74.56	91.39	86.44
21	21	91.12	.....	88.44	.....	103.33	.....
22	22	74.42	82.77	82.33	85.38	64.17	83.75
23	23	79.99	.....	66.97	.....	78.87	.....
24	24	66.80	73.38	81.14	74.07	51.25	65.06
25	25	75.01	.....	143.08	.....	87.67	.....
26	26	110.17	92.59	69.65	106.36	91.39	89.53
27	27	108.41	.....	152.72	.....	83.95	.....
28	28	132.14	120.27	51.07	101.89	87.08	85.51
29	29	66.51	.....	94.56	.....	68.10	.....
30	30	77.35	71.93	102.03	98.29	70.65	69.37
31	31	77.65	.....	122.01*	.....	73.97	.....
32	32	67.98	72.81	81.78	81.78	72.99	73.48
33	33	79.40	.....	52.70	.....	65.17	.....
34	34	89.37	84.38	56.82	55.76	62.82	63.99
35	35	66.50	.....	129.75	.....	62.43	.....
36	36	67.68	67.24	106.11	117.93	88.85	75.64

*Results omitted from the averages.

tion method as has been noted, and this fact, together with the shorter incubation period, explains the low results secured.

It is a commonly recognized fact that the magnesium oxide method for ammonia gives more than just the ammonia present as such in the soil, breaking down as it does certain amino-compounds and liberating ammonia from them while the aeration method liberates only the ammonia present as such in the soil. The manipulation of the aeration method is somewhat difficult and especially was it difficult to keep the entire one hundred grams of soil used in each test, in motion such as is necessary for accurate results, hence the method was not used for the other tests. The results with magnesium oxide may not be absolutely accurate for ammonia as such, therefore, but they are comparative at least, which, after all, is the main consideration in the ammonification studies reported in this work.

The duplicate determinations, as is usually the case with dried blood, did not agree very closely. This is the chief objection to the dried blood method, and is due partially to the lack of uniformity in the composition of the dried blood, partially to the difficulty of thorough mixing with the soil and in large part to the difficulty in distilling, owing to the foaming. In some instances where the results were clearly abnormal they were not included in the averages.

Considering now the results in Table VI, it is apparent that the different materials affected quite differently the ammonifying power of the soils as determined by the dried blood method.

The effects of treatment were much more pronounced than in the case of the casein method. None of the materials applied occasioned any decrease in ammonifying power, and hence the slight depressions noted in a few cases with the casein were evidently due, as has been concluded, to an absence of indications of effect rather than to an actual depression of ammonifying power.

Again, it appears that the manures favored the ammonifying process to a very large extent. With only one exception the manures all showed greater effects on the ammonifying bacteria than any of the other materials applied. The rotted manure gave a greater influence than the cow or horse manure. It will be recalled that the rotted manure had the narrowest ratio of any of the materials applied to the soil and it gives here the greatest effect on the ammonifying power of the soil.

The general influence of the horse manure was about the same as that of the cow manure, the horse manure having a slight advantage. The nitrogen-carbon ratio of these manures was quite different, that of the cow manure being much narrower than that of the horse manure, so that it appears here that the difference in ratio had little effect on the influence exerted by the materials on ammonification.

The most surprising results were those from the soils treated with the timothy hay which were about as high as those from the soils receiving rotted manure, and higher in almost every case than those from the soils where the horse and cow manures were used. The timothy hay had a wide nitrogen-carbon ratio, very much wider than the other materials except the oat straw and it might seem, therefore, that materials of wide nitrogen-carbon ratio would exert as much effect on ammonification as those of a narrow ratio. When the results with oat straw are considered, however, it is found that the effects on the ammonifying bacteria were much less than the influence exerted by the manures and even less than the effect of the hays which had a narrower nitrogen-carbon ratio.

TABLE VI.
THE AMMONIFICATION OF DRIED BLOOD.

Pot No.	Treatment.	I.		II.		III.	
		Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.
1	Check	77.07		29.09			
2	Check	73.28	75.14	29.06	29.07	42.15	42.15
3	Horse manure	94.43		50.95		62.52	
4	Horse manure	94.58	94.50	37.70	44.32	78.36	70.44
5	Cow manure	106.74		33.55		52.34	
6	Cow manure	81.77	94.28	59.69	46.62	75.53	63.43
7	Rotted manure	111.55		50.96		90.81	
8	Rotted manure	106.51	109.00	56.13	53.54	73.21	82.01
9	Oat straw	84.10		52.16		97.60	
10	Oat straw	85.60	84.85	42.01	47.08	51.20	74.40
11	Corn stover	85.58		51.81		43.85	
12	Corn stover	83.43	84.50	51.13	51.47	68.74	56.29
13	Timothy hay	94.36		64.12		63.65	
14	Timothy hay	105.05	99.70	59.62	62.02	67.05	65.35
15	Cowpea hay	75.01		43.87		61.39	
16	Cowpea hay	85.24	80.12	57.46	50.16	51.77	56.58
17	Clover hay	81.37		50.65		57.43	
18	Clover hay	87.14	84.25	51.14	50.89		57.43

Pot No.	Treatment.	IV.		V.		VI.	
		Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.	Ammonia Mg. N.	Average Mg. N.
1	Check			47.27		57.73	
2	Check	49.37	49.37	43.73	45.50	67.71	62.72
3	Horse manure	75.01		65.45		92.45	
4	Horse manure	81.30	78.15	87.29	76.37	100.38	96.41
5	Cow manure	95.36		73.90		76.44	
6	Cow manure	104.89	100.13	83.48	78.69	100.39	88.41
7	Rotted manure	103.43		50.73		79.65	
8	Rotted manure	112.56	107.89	84.91	67.82	99.89	89.77
9	Oat straw	59.18		60.58		64.95	
10	Oat straw	82.77	70.97	74.56	67.57	86.44	75.72
11	Corn stover	82.77		85.38		83.75	
12	Corn stover	73.38	78.07	74.07	79.72	65.06	74.40
13	Timothy hay	92.59		106.36		89.53	
14	Timothy hay	120.27	106.43	101.89	104.12	85.51	87.52
15	Cowpea hay	71.93		98.29		69.37	
16	Cowpea hay	72.81	72.37	81.78	90.03	73.48	71.42
17	Clover hay	84.38		55.76		63.99	
18	Clover hay	67.24	75.81	117.93	86.84	75.64	69.81

Practically the same situation obtained in the case of the corn stover, and the effect on the ammonifying bacteria was less than that exerted by the manures and hays, which had narrower ratios of nitrogen and carbon. It seems, therefore, that the nitrogen-carbon ratio in the common humus-forming materials had very little influence on the extent of the action exerted on the ammonifying bacteria.

The cowpea hay and clover hay uniformly exerted less influence on the ammonifying process than the manures and the timothy hay but they showed more effect than the oat straw and corn stover, although the differences were not very great and there were some variations in effects shown at the different samplings.

It is apparent, therefore, that some other factors than the nitrogen-carbon ratio in the materials used in this work must be of more importance in determining the effect on the ammonifying bacteria. It is probable that the character of the chemical compounds present in the materials used would explain the variations noted, for the different substances are made up, of course, of very different chemical substances, and while these differences would not appear from the analyses for carbon and nitrogen, they are undoubtedly present and of much significance from the standpoint of effects on bacterial activities.

It will be recalled that the materials used were all applied in a dried condition so that the variations noted were not due to the bacterial content of the substances. Of course, different quantities of the different materials were used, amounts such as are common on the farm being employed. These differences in applications would probably account partially for some of the results noted, such for instance, as the greater effect of the manures, but inasmuch as the results are to be interpreted from the field standpoint it was necessary to make field applications and these differences in amounts are inherent in farm practice.

In general, therefore, it appears from these results that applications of the common humus-forming materials in maximum amounts employed on the farm led to increases in the ammonifying power of the soil. Furthermore, these increases were apparently independent of the nitrogen-carbon ratio of the materials added and probably dependent on the chemical composition of the substances. The manures gave the greatest effects in most cases, although the timothy hay used in this work gave a greater influence than the horse manure or the cow manure. In the field, under ordinary farm conditions, when the manures are applied in a fresh condition and teeming with bacteria, a greater effect of the manures on ammonification would be expected.

Similarly, while the rotted manure gave the greatest influence in these results, in the field, it is probable that the fresh manures would show more effect because of the bacteria added.

If the soil employed had possessed a narrower nitrogen-carbon ratio, the differences in the results secured might have been more pronounced, so that any conclusion from this work must be qualified by specifying for *this particular soil which possessed a satisfactorily wide nitrogen-carbon ratio*. With this qualification, then, the statement previously made may be accepted as a rather definite conclusion from these results, namely, that the nitrogen-carbon ratio of common humus-forming materials, used in

maximum field applications had little or no effect on the influence exerted by these substances on ammonification in *this particular soil*. The different effects were probably due to the variations in chemical composition of the materials used.

Comparing the results of the ammonification tests as a whole, using the casein and the dried blood methods, it is apparent that the latter allows of much greater differentiation between the ammonifying power of soils differently treated. The casein method permits of the securing of much better agreement among duplicate determinations, but this point is of minor importance to the securing of results distinguishing more widely between ammonification in different soils. Some further modification in the technique of the casein method may remedy the difficulty mentioned, but until such a change is made the dried blood method must be considered the more satisfactory.

THE NITRIFICATION EXPERIMENTS.

To determine the effect of the various materials used in this work on the nitrifying power of the soil, samples secured on the dates previously mentioned were tested by the ammonium-sulfate-fresh-soil method as has been described. The tests on February 12, were incubated for 27 days and all the other tests were made in 28 days.

The results of the determinations are given in Tables VII, and the average results appear in Table VIII.

A few of the results are omitted from the averages because of evident abnormality. It will be noted, however, that as a whole the duplicate determinations agreed very satisfactorily.

Considering now the results given in Table VIII, it appears that the differences in nitrifying power were not pronounced. In general it seems, however, that the cowpea hay and clover hay had the greatest action on the nitrifiers and the manures a lesser effect, while the straws, stover and timothy hay showed little influence on nitrification. The differences were too slight to warrant definite conclusions in the case of the three latter materials, and hence the only statement which can be made is that these materials exerted practically no influence on nitrification. The small variations in the nitrifying power of the soils used in this work might have been increased by a longer incubation period. It seems that possibly larger differences might have been found with variations in the method employed, but from the standpoint of these experiments it is apparent that the nitrogen-carbon ratio of the materials used had no effect on the influence of the substances on the nitrifying power of the soils. The effects of the materials were apparently exerted on nitrification regardless of the ratio of nitrogen to carbon in them and dependent probably as in the case of ammonification on the chemical compounds present in the materials.

TABLE VII.
THE NITRIFICATION OF AMMONIUM SULFATE.

Pot. No.	Lab. No.	I. December 24.		II. January 7.		III. January 28.	
		Nitrate Mg. N.	Average Mg. N.	Nitrate Mg. N.	Average Mg. N.	Nitrate Mg. N.	Average Mg. N.
1	1	20.41	.....	19.74	.....	17.04	.....
2	2	20.83	20.62	19.99	19.36	17.04	17.04
3	3	20.83	.....	19.74	19.36	16.85	16.94
4	4	20.83	20.83	19.74	19.36	16.85	16.94
5	5	20.83	.....	20.00	.....	18.99	.....
6	6	21.23	21.53	19.74	19.87	18.99	18.99
7	7	21.73	.....	20.00	.....	18.52	.....
8	8	21.23	21.48	19.59	19.87	16.85	17.68
9	9	22.22	.....	22.06	.....	16.48	.....
10	10	22.72	22.46	22.40	22.23	16.48	16.48
11	11	20.41	.....	23.81	.....	18.52	.....
12	12	21.73	21.07	24.19	24.00	16.48	17.50
13	13	21.73	.....	22.73	.....	13.96	.....
14	14	21.73	21.73	22.39	22.56	16.85	16.90
15	15	22.22	.....	21.74	.....	16.85	.....
16	16	22.72	22.47	22.40	22.07	17.04	16.94
17	17	20.83	.....	21.13	.....	17.04	.....
18	18	21.23	21.03	20.83	20.98	16.85	16.94
19	19	21.23	.....	21.13	.....	17.04	.....
20	20	20.83	21.03	21.13	21.13	16.85	16.94
21	21	20.83	.....	20.27	.....	17.65	.....
22	22	21.23	21.03	20.48	20.37	16.99	17.32
23	23	21.23	.....	18.75	.....	18.07	.....
24	24	20.83	21.03	18.99	18.87	15.96	17.01
25	25	20.41	.....	22.06	.....	16.85	.....
26	26	20.83	20.62	21.74	21.90	17.04	16.94
27	27	20.83	.....	22.06	.....	16.66	.....
28	28	20.83	20.83	21.74	21.90	17.44	17.05
29	29	21.23	.....	25.64	.....	18.99	.....
30	30	21.73	21.48	24.59	25.61	18.75	18.87
31	31	21.23	.....	25.86	.....	19.48	.....
32	32	21.23	21.23	25.42	25.64	18.52	19.00
33	33	21.23	.....	23.81	.....	18.52	.....
34	34	21.73	21.48	23.40	23.60	17.04	17.78
35	35	21.23	.....	23.40	.....	18.52	.....
36	36	22.22	21.72	23.40	23.40	17.65	18.08

Pot. No.	Lab. No.	IV. February 12.		V. February 26.		VI. March 12.	
		Nitrate Mg. N.	Average Mg. N.	Nitrate Mg. N.	Average Mg. N.	Nitrate Mg. N.	Average Mg. N.
1	1	20.83	.....	22.06	.....	24.19	.....
2	2	21.43	21.13	21.74	21.90	23.40	23.79
3	3	19.74	.....	20.27	.....	24.57	.....
4	4	21.43	20.58	22.06	21.16	23.40	23.98
5	5	18.75	.....	22.06	.....	28.47	.....
6	6	19.59	19.17	21.74	21.90	22.40	25.43
7	7	20.00	.....	22.06	.....	22.40	.....
8	8	19.74	19.87	22.06	22.06	25.86	24.13
9	9	22.39	.....	22.06	.....	25.86	.....
10	10	21.43	21.91	22.39	22.22	27.77	26.81
11	11	19.23	.....	22.73	.....	25.42	.....
12	12	21.74	20.43	21.43	22.08	27.77	26.59
13	13	22.73	.....	22.40	.....	26.31	.....
14	14	23.40	23.06	24.57	23.48	23.40	24.85
15	15	20.27	.....	21.74	.....	27.77	.....
16	16	20.27	20.27	24.57	23.15	24.19	25.98
17	17	20.55	.....	22.73	.....	23.81	.....
18	18	20.55	20.55	19.74	21.23	22.40	23.10
19	19	18.07*	.....	22.06	.....	26.31	.....
20	20	17.65*	.....	18.75*	22.06	23.81	25.06
21	21	18.99	.....	22.06	.....	25.42	.....
22	22	20.83	19.91	20.27	21.16	26.31	25.86
23	23	20.27	.....	22.06	.....	25.42	.....
24	24	22.06	21.16	19.23*	22.06	22.40	23.91
25	25	18.07*	.....	20.00	.....	25.42	.....
26	26	20.27	20.27	20.27	20.13	23.81	24.61
27	27	19.74*	.....	22.06	.....	25.00	.....
28	28	21.43	21.43	21.74	21.90	24.57	24.78
29	29	22.73	.....	22.73	.....	27.27	.....
30	30	22.40	22.56	23.81	23.27	25.42	26.34
31	31	22.40	.....	24.19	.....	27.27	.....
32	32	23.81	23.10	23.40	23.79	25.86	26.56
33	33	20.55	.....	22.39	.....	27.77	.....
34	34	22.73	21.64	20.55	21.47	25.42	26.59
35	35	23.40	.....	24.19	.....	26.78	.....
36	36	20.00	21.70	20.83	22.51	27.77	27.27

*Results omitted from the averages.

TABLE VIII.
THE NITRIFICATION OF AMMONIUM SULFATE.

Pot No.	Treatment.	I.		II.		III.	
		Average Mg. N.	Nitrate Mg. N.	Average Mg. N.	Nitrate Mg. N.	Nitrate Mg. N.	Average Mg. N.
1	Check	20.62		19.36		17.04	
2	Check	20.83	20.72	19.36	19.36	16.94	16.99
3	Horse manure	21.53		19.87		18.99	
4	Horse manure	21.48	21.50	19.78	19.82	17.68	18.33
5	Cow manure	22.46		22.23		16.48	
6	Cow manure	21.07	21.76	24.00	23.11	17.50	16.99
7	Rotted manure	21.73		22.56		16.90	
8	Rotted manure	22.47	22.10	22.07	22.31	16.94	16.92
9	Oat straw	21.03		20.98		16.94	
10	Oat straw	21.03	21.03	21.13	21.05	16.94	16.94
11	Corn stover	21.03		20.37		17.32	
12	Corn stover	21.03	21.03	18.87	19.62	17.01	17.16
13	Timothy hay	20.62		21.90		16.94	
14	Timothy hay	20.83	20.72	21.90	21.90	17.05	16.99
15	Cowpea hay	21.48		25.61		18.87	
16	Cowpea hay	21.23	21.35	25.64	25.62	19.00	18.93
17	Clover hay	21.48		23.60		17.78	
18	Clover hay	21.72	21.60	23.40	23.50	18.08	17.93

Pot No.	Treatment.	IV.		V.		VI.	
		Nitrate Mg. N.	Average Mg. N.	Nitrate Mg. N.	Average Mg. N.	Nitrate Mg. N.	Average Mg. N.
1	Check	21.13		21.90		23.79	
2	Check	20.58	20.85	21.16	21.53	23.98	23.88
3	Horse manure	19.17		21.90		25.43	
4	Horse manure	19.87	19.52	22.06	21.98	24.13	24.78
5	Cow manure	21.91		22.22		26.81	
6	Cow manure	20.43	21.17	22.08	22.15	26.59	26.70
7	Rotted manure	23.06		23.48		24.85	
8	Rotted manure	20.27	21.66	23.15	23.31	25.98	25.91
9	Oat straw	20.55		21.23		23.10	
10	Oat straw		20.55	22.06	21.64	25.06	24.08
11	Corn stover	19.91		21.16		25.86	
12	Corn stover	21.16	20.53	22.06	21.61	23.91	24.88
13	Timothy hay	20.27		20.13		24.61	
14	Timothy hay	21.43	20.85	21.90	21.01	24.78	24.69
15	Cowpea hay	22.56		23.27		26.34	
16	Cowpea hay	23.10	22.83	23.79	23.53	26.56	26.45
17	Clover hay	21.64		21.47		26.59	
18	Clover hay	21.70	21.67	22.51	21.99	27.27	26.93

It is interesting to note that the manure which exerted the greatest effect on ammonification showed also comparatively large effects on nitrification, while the legume hays which showed lesser effects on ammonification than the manures gave a greater influence on nitrification. Just why this should be the case is difficult to determine as ordinarily materials which favor ammonification in field soils will favor also nitrification, unless the amounts of organic matter added are so large that nitrification is entirely inhibited. It seems to be a matter of considerable doubt at present whether it is possible to add sufficient organic matter to field soils to prevent nitrification. However that may be, it is apparent here that nitrification was not restricted by any of the maximum applications of the common materials used and ammonification was increased as described, hence it might be expected that the effects would be in the same direction for both processes. It is possible, however, that different materials might increase both processes, but to different degrees.

It is important to note, however, from these results that the common humus-forming materials, such as are used on the farm when applied in

maximum amounts did not depress the nitrifying power of the soil, at least of this particular soil. On the other hand, there was an increase in nitrification to a more or less pronounced extent with the different materials. In the case of soils containing more organic matter or material of a narrower nitrogen-carbon ratio, it is difficult to predict the effect, but inasmuch as organic matter in such large amounts as were used here, particularly in the case of the leguminous green manures, would not be used unless the soils were low in nitrogen, it seems safe to say that there is no danger of restricting nitrification in soils by additions of amounts of organic matter such as would be used in the field.

In general from these experiments it is apparent that nitrification was increased by additions of organic materials such as are made on the farm, and these increases were independent of the nitrogen-carbon ratio in the materials, although there were some indications that the materials of a narrower ratio gave a greater effect than those of a wider ratio, but the results were not conclusive. Inasmuch as the latter possibility is the opposite of the case with ammonification, it is apparent that more definite results must be secured before any conclusions should be drawn.

THE AZOFICATION EXPERIMENTS.

The samples drawn on the six dates mentioned previously were tested for their azofying or nitrogen-fixing power by the fresh-soil method. At the first sampling, mannite (5 gm. per 100 gm. of soil) was used and at the later dates dextrose was employed, being added from solution at the rate of 3 gm. per 100 gm. of soil.

The incubation period was eleven days, except in the case of the second sampling when the tests were allowed to incubate fourteen days.

The complete results of the tests are given in Table IX and the summarized results appear in Table X.

As might be expected, there were considerable variations in the results of the duplicate determinations. The method used for the determination of total nitrogen does not permit of the estimation of such small amounts of nitrogen as sometimes represent the nitrogen fixation. In some instances a smaller amount of nitrogen was actually found after the incubation period, but it was hardly possible for any loss of nitrogen to occur and hence such results should be attributed to the fact that the method is not accurate for small amounts of nitrogen. These low results are eliminated from the averages and are interpreted merely as representing, therefore, the absence of any azofication.

In calculating the results, the total nitrogen present in the soils in the tests before incubation was estimated and the nitrogen present at the end subtracted to determine the amount of nitrogen fixed. A slight error is, of course, introduced here in case not all of the mannite or dextrose added was used by the bacteria when the unused portion would be included

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TABLE IX.
AZOFICATION.

I. December 24.						II. January 7.		
Pot No.	Lab. No.	N. in Orig. Soil Mg.	N. after incub. Mg.	N. fixed Mg.	Average Mg.	N. after incub. Mg.	N. fixed Mg.	Average Mg.
1	1	98.80	99.50	.70	.....	110.10	11.30	.....
..	2	98.80	98.80	.00	.....	110.20	1.40	6.35
2	3	98.80	102.30	3.50	.35	104.40	5.60	.....
..	4	98.80	100.90	2.10	2.80	105.80	7.00	6.30
3	5	106.56	110.80	4.24	.....	115.70	9.14	.....
..	6	106.56	107.20	.64	2.44	115.70	9.14	9.14
4	7	106.56	107.20	.64	.....	115.00	8.44	.....
..	8	106.56	105.10	-1.46*	.64	115.70	9.14	8.79
5	9	107.62	110.10	2.48	.....	119.90	12.28	.....
..	10	107.62	111.50	3.88	3.18	115.00	7.38	9.83
6	11	107.62	110.10	2.48	.....	118.50	10.88	.....
..	12	107.62	111.50	3.88	3.18	115.70	8.08	9.48
7	13	111.32	111.50	.18	.....	117.80	6.48	.....
..	14	111.32	111.50	.18	.18	122.80	11.48	8.98
8	15	111.32	105.80	-5.52*	.....	119.90	8.58	.....
..	16	111.32	113.60	2.28	2.28	121.40	10.08	9.08
9	17	100.97	104.40	3.43	.....	105.80	4.83	.....
..	18	100.97	107.20	6.23	3.83	104.40	3.43	4.13
10	19	100.97	100.20	-.77*	.....	112.90	11.93	.....
..	20	100.97	101.50	.53	.53	108.60	7.63	9.78
11	21	103.23	105.80	2.57	.....	109.40	6.17	.....
..	22	103.23	107.90	4.67	3.62	111.50	8.27	7.22
12	23	103.23	100.90	2.33	.....	108.60	5.37	.....
..	24	103.23	106.50	3.27	2.80	111.50	8.27	6.82
13	25	100.75	103.00	2.25	.....	105.80	5.05	.....
..	26	100.75	105.10	4.35	3.30	114.30	13.55	9.30
14	27	100.75	102.30	1.55	.....	108.60	7.85	.....
..	28	100.75	107.20	6.45	4.00	109.40	8.65	8.25
15	29	107.55	108.60	1.05	.....	112.20	4.65	.....
..	30	107.55	107.20	-.35*	1.05	112.90	5.35	5.00
16	31	107.55	107.20	-.35*	.....	111.50	3.95	.....
..	32	107.55	107.20	-.35*	.....	112.20	4.65	4.30
17	33	107.03	110.10	3.07	.....	111.50	4.47	.....
..	34	107.03	103.00	-4.03*	3.07	108.60	1.57	3.02
18	35	107.03	108.00	.97	.....	112.90	5.87	.....
..	36	107.03	107.20	.17	.57	115.70	4.47	5.17

III. January 28.						IV. February 12.		
Pot No.	Lab. No.	N. in Orig. Soil Mg.	N. after incub. Mg.	N. fixed Mg.	Average Mg.	N. after incub. Mg.	N. fixed Mg.	Average Mg.
1	1	98.80	102.10	3.30	.....	102.30	3.50	.....
..	2	98.80	111.50	12.70	8.10	100.90	2.10	2.80
2	3	98.80	105.80	7.00	.....	98.80	.00	.....
..	4	98.80	104.40	5.60	6.30	107.20	8.40	4.20
3	5	106.56	122.10	15.54	.....	110.80	4.24	.....
..	6	106.56	116.40	9.84	12.69	107.90	1.34	2.79
4	7	106.56	116.40	9.84	.....	112.20	5.64	.....
..	8	106.56	115.70	9.14	9.49	109.40	2.84	4.24
5	9	107.62	121.30	13.68	.....	111.50	3.88	.....
..	10	107.62	117.10	9.48	11.58	117.80	10.18	7.03
6	11	107.62	108.20	-.42*	.....	115.00	7.38	.....
..	12	107.62	119.20	11.58	11.58	111.50	3.88	5.63
7	13	111.32	117.10	5.78	.....	115.70	4.38	2.98
..	14	111.32	120.60	9.28	7.53	112.90	1.58	.....
8	15	111.32	122.80	11.48	.....	121.30	9.98	.....
..	16	111.32	131.20	19.88	10.68	115.70	4.38	7.18
9	17	100.97	112.20	11.23	.....	115.70	14.73	.....
..	18	100.97	112.90	11.93	11.58	111.50	10.53	12.63
10	19	100.97	117.10	16.13	.....	104.40	3.43	.....
..	20	100.97	112.90	11.93	14.03	107.20	6.23	4.83
11	21	103.23	107.20	3.97	.....	108.60	5.37	.....
..	22	103.23	105.80	2.57	3.27	104.40	1.17	3.27
12	23	103.23	111.50	8.27	.....	112.90	9.67	.....
..	24	103.23	109.40	6.17	7.22	107.90	4.67	7.17
13	25	100.75	105.80	5.05	.....	104.40	3.65	.....
..	26	100.75	104.40	3.65	4.35	108.60	7.85	5.75
14	27	100.75	103.00	2.25	.....	106.50	5.75	.....
..	28	100.75	108.60	7.85	5.05	104.40	3.65	4.70
15	29	107.55	112.90	5.35	.....	110.10	2.55	.....
..	30	107.55	115.00	7.45	6.40	105.10	-2.45*	2.55
16	31	107.55	116.40	8.85	.....	112.90	5.35	.....
..	32	107.55	112.20	4.65	6.75	112.20	4.65	5.00
17	33	107.03	113.60	6.57	.....	110.80	3.77	.....
..	34	107.03	114.30	7.27	6.92	108.60	1.57	2.67
18	35	107.03	108.60	1.57	.....	112.90	5.87	.....
..	36	107.03	111.50	4.47	3.02	110.10	3.07	4.47

*Results omitted from the averages.

TABLE IX. (Continued).

Pot No.	Lab. No.	N. in Orig. Soil Mg.	V. February 26.			VI. March 12.		
			N. after incub. Mg.	N. fixed Mg.	Average Mg.	N. after incub. Mg.	N. fixed Mg.	Average Mg.
1	1	98.80	103.70	4.90	.....	106.50	7.70	.....
..	2	98.80	100.90	2.10	3.50	105.10	6.30	7.00
2	3	98.80	103.70	4.90	.....	105.80	7.00	.....
..	4	98.80	103.00	4.20	4.55	107.20	8.40	7.70
3	5	106.56	108.60	2.04	.....	117.10	10.54	.....
..	6	106.56	110.10	3.54	2.79	118.50	11.94	11.24
4	7	106.56	107.20	.66	.....	115.00	8.44	.....
..	8	106.56	115.70	9.14	4.70	118.50	11.94	10.19
5	9	107.62	111.50	3.88	.....	118.50	10.88	.....
..	10	107.62	119.90	12.28	8.08	125.60	17.98	14.43
6	11	107.62	119.90	12.28	.....	120.60	12.98	.....
..	12	107.62	112.90	5.28	8.78	115.70	8.08	10.53
7	13	111.32	115.00	3.68	.....	115.00	3.68	.....
..	14	111.32	115.70	4.38	4.03	127.70	16.38	10.03
8	15	111.32	113.60	2.28	.....	122.80	11.48	.....
..	16	111.32	118.50	7.18	4.73	127.00	15.68	13.58
9	17	100.97	108.60	7.63	.....	106.50	5.53	.....
..	18	100.97	108.60	7.63	7.63	108.60	7.63	6.58
10	19	100.97	105.10	4.23	.....	104.40	3.43	.....
..	20	100.97	111.50	10.53	7.38	112.90	11.93	7.66
11	21	103.23	107.20	3.97	.....	111.50	8.27	.....
..	22	103.23	110.10	6.87	5.42	106.50	3.27	5.77
12	23	103.23	107.90	4.67	.....	109.40	6.17	.....
..	24	103.23	110.80	7.57	6.12	110.10	6.87	6.52
13	25	100.75	107.20	6.45	.....	105.80	5.05	.....
..	26	100.75	104.40	3.65	5.05	112.90	12.15	8.60
14	27	100.75	107.20	6.45	.....	110.10	9.35	.....
..	28	100.75	112.90	12.15	9.30	109.40	8.65	9.00
15	29	107.55	113.60	6.05	.....	108.60	1.05	.....
..	30	107.55	107.20	— .35*	6.05	110.10	2.55	1.80
16	31	107.55	110.10	2.55	.....	108.60	1.05	.....
..	32	107.55	107.90	.35	1.45	112.20	4.65	2.85
17	33	107.03	110.10	3.07	.....	109.40	3.07	.....
..	34	107.03	111.50	4.47	3.77	110.10	3.07	2.72
18	35	107.03	110.10	3.07	.....	112.20	5.17	.....
..	36	107.03	111.50	4.47	3.77	109.40	2.37	3.77

*Results omitted from the averages.

in the sample analyzed after incubation. In such a case the results would be slightly lower than they should be, hence the amounts of nitrogen fixed from the atmosphere may be too low, but that fact need not interfere with the interpretation of the results.

Considering the results given in Table X, it is apparent that the addition of various organic materials to the soil influenced to a considerable extent the fixation of nitrogen by non-symbiotic bacteria. In some cases the amount of nitrogen fixed in the eleven-day incubation period amounted to one-sixth of the nitrogen originally present in the soil.

The soils receiving cow manure and oat straw showed for the most part the greatest increase in azofying power and the influence of the rotted manure was only slightly less than that of the cow manure.

The horse manure gave less effect than the other manures and about the same in most cases as the timothy hay. The corn stover also affected the azofying power of the soil to about the same extent as the horse manure.

The cowpea hay and the clover hay exerted the smallest effect of any of the materials on the azofying power of the soil.

It appears, therefore, from the results as a whole that the nitrogen-carbon ratio of the various humus-forming materials applied to the soil was of little significance from the standpoint of the effect on azofication. The influence of the materials was exerted regardless of the nitrogen-carbon ratio. Thus the oat straw of a wide ratio and the cow manure of a narrower ratio had about the same effect. Similarly the timothy hay and the horse manure of wide and narrow ratios respectively had considerable influence. Again the rotted manure of a very narrow ratio exerted as much effect on azofication as the timothy hay which had a wide ratio.

TABLE X.
AZOFICATION.

Pot No.	Treatment.	I.		II.		III.	
		N. fixed Mg.	Average Mg.	N. fixed Mg.	Average Mg.	N. fixed Mg.	Average Mg.
1	Check	.35		6.35		8.10	
2	Check	2.80	1.57	6.30	6.32	6.30	7.20
3	Horse manure	2.44		9.14		12.69	
4	Horse manure	.64	1.54	8.79	8.96	9.49	11.09
5	Cow manure	3.18		9.83		11.58	
6	Cow manure	3.18	3.18	9.48	9.65	11.58	11.58
7	Rotted manure	.18	1.23	8.98		7.53	
8	Rotted manure	2.28		9.33	9.15	10.68	9.10
9	Oat straw	3.83		4.13		11.58	
10	Oat straw	.53	2.18	9.78	6.95	14.03	12.80
11	Corn stover	3.62		7.22		3.27	
12	Corn stover	2.80	3.21	6.82	7.02	7.22	5.24
13	Timothy hay	3.30		9.30		4.35	
14	Timothy hay	4.00	3.85	8.25	8.77	5.05	4.70
15	Cowpea hay	1.05		5.00		6.40	
16	Cowpea hay		1.05	4.30	4.65	6.75	6.57
17	Clover hay	3.07		3.02		6.92	
18	Clover hay	.57	1.82	5.17	4.09	3.02	4.97

Pot No.	Treatment.	IV.		V.		VI.	
		N. fixed Mg.	Average Mg.	N. fixed Mg.	Average Mg.	N. fixed Mg.	Average Mg.
1	Check	2.80		3.50		7.00	
2	Check	4.20	3.50	4.55	4.02	7.70	7.35
3	Horse manure	2.79		2.79		11.24	
4	Horse manure	4.24	3.51	4.70	3.74	10.19	10.71
5	Cow manure	7.03		8.08		14.43	
6	Cow manure	5.63	6.33	8.78	8.43	10.53	12.48
7	Rotted manure	2.98		4.03		10.03	
8	Rotted manure	7.18	5.08	4.73	4.38	13.58	11.80
9	Oat straw	12.63		7.63		6.58	
10	Oat straw	4.83	8.73	7.38	7.50	7.66	7.12
11	Corn stover	3.27		5.42		5.77	
12	Corn stover	7.17	5.19	6.12	5.79	6.52	6.14
13	Timothy hay	5.75		5.05		8.60	
14	Timothy hay	4.70	5.22	9.30	7.17	9.00	8.80
15	Cowpea hay	2.55		6.05		1.80	
16	Cowpea hay	5.00	3.77	1.45	3.75	2.85	2.32
17	Clover hay	2.67		3.77		2.72	
18	Clover hay	4.47	3.57	3.77	3.77	3.77	3.24

To just what influence of the materials the difference in results was due would be difficult to determine. It may be that the difference in chemical composition of the substances would explain the results. This was the conclusion reached in the ammonification and nitrification experiments and would probably hold true here. It is well known that organic compounds of different composition exert quite different effects on the azotobacter and hence the results from the use of the materials employed

here might be expected, to the extent at least that the different materials had various effects. The important point in this connection which these results bring out is that the character of the compounds present apparently determined the results and the ratio of the nitrogen to carbon present gave no indication of the effects to be expected.

It is interesting to note further that the leguminous hays had much less effect on the azofying power of the soil than the other materials. Especially is this point worthy of mention because of the relative effects of the legumes and non-legumes for green manures. If the latter materials will increase the fixation of nitrogen from the atmosphere by the non-symbiotic azotobacter sufficiently to supply as much nitrogen for the use of crops as is added in legume crops, such materials might frequently be preferable for use on soils. It is impossible from these results to ascertain whether such is the case or not. Further results must be secured with complete field experiments before definite conclusions can be reached.

These results do show, however, that the non-legumes increased the azofying power of the soil to a much greater extent than the legumes. This greater effect was probably due as has been mentioned to the chemical composition of the materials. In this case the effects are in the same direction as the widening of the nitrogen-carbon ratio, and it might seem that the ratio of the materials would indicate the influence on azofication, but inasmuch as the manures of narrower nitrogen-carbon ratio had as much effect as the non-legumes and straws it would evidently not be warranted to draw any conclusion regarding the effects of the ratio in materials added on azofication.

In general then the results show that azofication was favored by manure to a large extent; that straw, stover and non-leguminous hays had almost as great an effect as the manures, although of a much wider nitrogen-carbon ratio, and that the leguminous hays had the least effect of any of the materials used in the experiment. Apparently, the nitrogen-carbon ratio of the materials used was of little or no significance in indicating their influence on azofication and differences in effects were due rather to variations in the chemical compounds present.

There are indications, however, that non-leguminous hays and straws may increase azofication in soils to a large enough extent to make their use more profitable than that of legumes which although adding nitrogen to the soil are somewhat more expensive to use.

These conclusions apply, of course, as must be emphasized again, only to this particular soil type and when the materials are used in amounts such as were employed here, that is, in maximum field applications. The results are, therefore, directly applicable to farm conditions on this soil type and may indicate what will occur on similar soils. Further experiments on the comparative effects of legumes and non-legumes

as green manures from the standpoint of their influence on azofication are extremely desirable and may lead to important practical conclusions.

One point further is worthy of mention in connection with these experiments and that is that the results secured with dextrose were much more satisfactory than those with mannite. The latter material has been considered the best for such work, but it is possible that the cheaper dextrose may serve as well or even better. The point is worthy of consideration in connection with extensive azofication experiments.

Comparing the azofication results as a whole with the ammonification and nitrification results, it appears that there was little similarity in the effects of the different materials on the different processes. Azofication was increased in some cases to a greater extent by some materials than by others, whereas the opposite was the case with ammonification and nitrification.

This fact brings up another important point in connection with the use on soils of organic materials which increase azofication to the greatest extent. Is it necessary that ammonification and nitrification should also be considered? This is a question which must be left for future rather extensive experiments to settle, and involves the whole question of the form in which plants may assimilate their nitrogen, a question which is apparently far from definitely settled as yet.

THE CROP YIELDS.

The crop of oats on the pots, the duplicates of which were kept bare for bacteriological tests, was harvested just prior to maturity, dried, ground and analyzed for total nitrogen. The green and dry weights of the crops are given in Table XI and the nitrogen content of the crop together with the calculated removal of nitrogen from the soil are given in Table XII.

TABLE XI.
THE CROP YIELDS.

Pot No.	Treatment.	Green Weight Gm.	Average Gm.	Dry Weight Gm.	Average Gm.
19	Check	189.0	.....	58.6	.....
20	Check	207.0	198.00	61.5	60.05
21	Horse manure	112.9	.....	30.3	.....
22	Horse manure	119.7	116.30	32.0	31.15
23	Cow manure	234.4	.....	70.6	.....
24	Cow manure	218.2	226.30	63.0	66.80
25	Rotted manure	279.6	.....	85.2	.....
26	Rotted manure	298.0	289.00	88.9	87.05
27	Oat straw	115.3	.....	32.5	.....
28	Oat straw	100.6	107.95	28.9	30.70
29	Corn stover	182.9	.....	50.0	.....
30	Corn stover	180.7	181.80	52.6	51.30
31	Timothy hay	143.2	.....	44.6	.....
32	Timothy hay	151.1	147.15	45.3	44.95
33	Cowpea hay	260.5	.....	72.4	.....
34	Cowpea hay	244.6	252.55	72.8	72.60
35	Clover hay	224.9	.....	63.6	.....
36	Clover hay	224.9	224.90	64.0	63.80

From examining the yields in Table XI, it appears that the rotted manure, the cow manure and the leguminous hays increased the crop yields to

a considerable extent. The horse manure depressed the yield over that of the untreated soil. The plants in these pots were weak and turned yellow soon after they appeared above the surface of the soil, but after about ten weeks this bad effect from the horse manure disappeared and the oats showed a more vigorous growth. If the experiment had continued longer, it is probable that the yields would have equalled those secured with the other materials. The depressing action was probably due to the introduction with the heavy application of manure of chemical substances which were injurious to the young plants.

All of the non-legume hays, straw and stover materials with a wide nitrogen-carbon ratio gave no increase in the crop yields. In fact, an actual depression in yields occurred. These materials apparently did not decompose sufficiently rapidly to aid the crop grown or the nitrogen content of the soil was more depleted than was believed. At any rate, the legume hays increased the yields, a fact which would indicate that the nitrogen factor on these soils was important and that the non-legumes did not increase the fixation of nitrogen from the atmosphere sufficiently to keep the oats supplied with that element.

The experiment, of course, was continued hardly long enough for definite crop results to be secured and a second crop was planted after the first was removed in order to determine whether different results would be secured, allowing a longer time for the organic material to decompose.

It appears from these first results, however, that the nitrogen-carbon ratio of the organic materials was of considerable significance in determining the effects of the materials used on the crop yields from this particular soil. In every case those substances with the narrower nitrogen-carbon ratios increased to the greatest extent the crop yields, while the materials of wide ratios decreased the crop yields. The nitrogen factor was evidently very important on this particular soil.

TABLE XII.
THE ANALYSES OF THE CROPS.

Pot No.	Treatment.	N. in Crop %	Average %	C. in Crop %	Average %	N—C Ratio	N. rem'd Gm.	Average Gm.
19	Check .....	.734	...	39.429	...	...	.430	...
20	Check .....	.730	.732	37.637	38.533	1:52.64	.449	.439
21	Horse manure .....	.818	...	41.911	...	...	.248	...
22	Horse manure .....	.861	.839	37.083	39.497	1:47.07	.276	...
23	Cow manure .....	.734	...	45.827	...	...	.518	...
24	Cow manure .....	.734	.734	45.372	45.599	1:62.11	.462	.490
25	Rotted manure .....	.776	...	40.413	...	...	.661	...
26	Rotted manure .....	.797	.786	37.367	38.890	1:49.48	.709	.685
27	Oat straw .....	.764	...	38.745	...	...	.248	...
28	Oat straw .....	.771	.767	39.140	38.943	1:50.77	.224	.236
29	Corn stover .....	.783	...	39.195	...	...	.392	...
30	Corn stover .....	.797	.790	37.254	38.225	1:48.37	.419	.405
31	Timothy hay .....	.709	...	38.653	...	...	.316	...
32	Timothy hay .....	.703	.706	39.985	39.319	1:55.69	.318	.317
33	Cowpea hay .....	.903	...	38.372	...	...	.654	...
34	Cowpea hay .....	.868	.885	38.806	38.590	1:43.60	.632	.643
35	Clover hay .....	.805	...	42.410	...	...	.512	...
36	Clover hay .....	.836	.820	44.443	43.427	1:52.96	.534	.523

In Table XII, it is seen that the percentage of nitrogen in the oats varied considerably, the tendency being for the lowest yields to show the highest nitrogen content. The largest crops, however, removed the greatest amount of nitrogen from the soil.

The crop yields as a whole show that materials such as ⁶were used in this work may exert a considerable influence on bacterial activities and not show the same effect on the crop grown. The effects on subsequent crops, however, would be a more definite indication of the relative values of these materials, because of the need of time for decomposition. In other words, it would not be expected that the effects of such materials on crops would be exerted as soon as effects on bacterial activities. The latter must always precede the former. Hence some time should elapse after applying organic materials before the effect on the crop grown is determined. If the effects of materials of wide nitrogen-carbon ratio are dependent to any extent on the increase in nitrogen content of the soil through non-symbiotic nitrogen-fixation, time should be allowed for this process to occur before the comparative effects on crop yields are tested. It is not regarded, therefore, that these crop yields present facts which oppose in any way the possibility of sufficient azofication occurring in soils treated with non-legumes to equal the effects caused by legumes.

THE SECOND CROP YIELDS.

The second crop of oats grown on the same soils as in the case of the first crop was harvested before it had attained any considerable growth. The yields given in Table XIII, however, show some interesting relations to those of the first crop.

TABLE XIII.
THE SECOND CROP YIELDS.

Pot No.	Treatment.	Green Weight Gm.	Average Gm.	Dry Weight Gm.	Average Gm.
19	Cheek	26.7	.....	6.5	.....
20	Cheek	32.3	29.50	7.7	7.1
21	Horse manure	47.7	.....	11.6	.....
22	Horse manure	57.0	52.35	12.7	12.15
23	Cow manure	49.9	.....	12.8	.....
24	Cow manure	57.95	53.92	15.0	13.9
25	Rotted manure	34.0	.....	7.4	.....
26	Rotted manure	39.5	36.75	9.2	8.3
27	Oat straw	41.7	.....	10.0	.....
28	Oat straw	49.55	45.62	12.2	11.1
29	Corn stover	56.65	.....	11.5	.....
30	Corn stover	43.2	49.92	10.0	10.75
31	Timothy hay	38.6	.....	7.0	.....
32	Timothy hay	43.4	41.00	11.2	9.1
33	Cowpea hay	37.3	.....	9.0	.....
34	Cowpea hay	51.1	44.20	12.2	10.6
35	Clover hay	44.5	.....	9.5	.....
36	Clover hay	41.15	42.82	9.5	9.5

In this case, all the treatments increased the oats growth, but the horse and cow manures gave the largest effect here, while the rotted manure gave a smaller effect than any of the other materials. With the first crop, the rotted manure gave the greatest influence, while the cow manure

hardly increased the yield and the horse manure depressed the oats growth. Evidently the cause of the injurious action of the horse manure had disappeared before the second crop was grown, and only beneficial effects from the material were in evidence on the second crop.

The rotted manure had apparently lost much of its value for increasing the crop yield by the time the first crop was removed, and had little effect on the second crop.

The oat straw and corn stover gave greater yields than the legume hays and the timothy hay had only a slightly smaller effect than the clover and cowpeas. It is apparent, therefore, that the conclusion drawn in connection with the first yields was well warranted. The non-legumes here seemed to have a greater or as great an effect on the crop as the legumes. Evidently the nitrogen fixed by azofiers was sufficient to supply the second crop of oats with as much of that element as was furnished by the legumes. Of course, there was probably some neutralizing action here as might be expected. If the first crop of oats took out much more nitrogen where the legumes were used than where the other materials were applied, the second crop might be not as well supplied as in the case of the non-legumes because of a shortage of nitrogen. Such could hardly be the case here, however, to more than a negligible extent, hence the conclusion seems justified that non-legumes may be as beneficial as legumes on crops grown, provided sufficient time is allowed to elapse between the application of the materials and the growth of the crop, for decomposition to occur and the fixation of nitrogen from the atmosphere to take place.

There is much closer agreement between the effects of the various materials on bacterial activities and on the second crop of oats than with the first crop. It will be recalled that the first crop of oats was seeded as soon as the substances were added, and it appears from these results that the influence of many of these common humus-forming substances on crops is much greater if time is allowed for decomposition and for other affected bacterial processes to occur before the crop is grown.

The nitrogen-carbon ratio of the various substances did not seem to be of as much importance in determining their effect on the second crop of oats as with the first crop, although there were indications that the materials with wider ratios had more effect than those with narrower ratios.

SUMMARY.

The results of these experiments on this particular soil type lead to the following conclusions.

1. Applications of the common humus-forming materials in maximum amounts for farm conditions and in a dried condition increased bacterial activities, ammonification, nitrification and azofication to a considerable extent.

2. The manures, horse manure, cow manure and rotted manure gave the greatest effect on ammonification in most cases, although timothy hay surpassed the horse manure and cow manure in the extent of its effect in several instances. The oat straw and corn stover had a lesser effect than the manures and the legume hays, clover and cowpeas showed the least effect on ammonification of any of the materials used.

3. Increases in ammonification due to the applications of humus-forming materials were independent of the nitrogen-carbon ratio of the materials added and were probably dependent on the chemical composition of the substances.

4. The relative effects of the various materials used would undoubtedly be somewhat altered for field conditions, because of the fact that they were applied in a dried condition. Especially in the case of the manures would the influence on ammonification be accentuated because of the actual addition of bacteria to the soil.

5. The dried-blood-fresh-soil method gave better results for ammonification than the casein-fresh-soil method. The latter gave better duplicate results, but the differences between different soils were not nearly so pronounced. Some further modification of the casein method seems necessary for its general use.

6. Nitrification was increased in much the same way as ammonification, by the various organic materials. The leguminous green manures exerted, however, somewhat greater effects than the manures, and also more influence than the non-legumes. These results were the opposite of those secured with ammonification, but the differences were not great enough to permit of definite conclusions.

7. Increases in nitrification brought about by the various materials were apparently independent of the nitrogen-carbon ratio in the substances. Indications of a greater effect of materials of a narrower ratio over those of a wide ratio cannot be considered conclusive.

8. Azofication or non-symbiotic nitrogen fixation was favored by manure to a large extent. Straw, stover and non-leguminous hays had almost as great an effect as the manures and the leguminous hays had the least effect of any of the materials used.

9. The nitrogen-carbon ratio of the materials employed were of little or no significance in indicating their effects on azofication. There were indications, however, that non-legumes and straws might increase azofication in soils to a large enough extent to make their use more profitable than that of legumes which add nitrogen to the soil, but are somewhat more expensive to use.

10. Further experiments carried on under field conditions to ascertain the relative effects of legumes and non-legumes on azofication are extremely desirable and results secured may be of great practical importance.

11. Dextrose gave better results in the azofication experiments than mannite and may, therefore, be substituted for the more expensive material.

12. There was little similarity between the effects of the different organic materials on the different bacterial processes. Is it necessary that the material which increases ammonification, nitrification and azofication be chosen for use in soils, or shall an increase in azofying power be sufficient to recommend the substance? This question cannot yet be answered.

13. The manures and legumes increased the first crop of oats, except in the case of the horse manure, which apparently exerted an injurious effect on the crop in its early stages of growth. This injury was disappearing when the oats were harvested and might have been unnoticed had the crop been grown for a longer period.

14. The substances with wide nitrogen-carbon ratio decreased the crop yield while those of narrow ratios gave increases. The nitrogen factor was evidently very important on this soil.

15. The nitrogen-carbon ratio of the organic materials seemed to be of importance in determining the influence on the first crop of oats.

16. If opportunity is to be given for non-legumes to exert as good an effect as legumes, by increasing azofication to a sufficient extent to offset the nitrogen supplied by the legumes, the organic materials must be allowed sufficient time for considerable decomposition to occur before a crop is grown to test the effects.

17. The influence of the various substances applied to the soils was noted on a second crop of oats, but the relative effects were different. The non-legumes had as great an influence as the legumes and hence previous conclusions are confirmed that with the use of the former materials sufficient time must be allowed to elapse for azofication to occur if as beneficial effects are to be secured as with legumes.

18. The nitrogen-carbon ratio of the materials applied to the soil did not seem to be of as much importance in determining the effect on the second crop of oats as in the case of the first crop.

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CARBON AND NITROGEN CHANGES IN THE SOIL VARIOUSLY TREATED: SOIL TREATED WITH LIME, AMMONIUM SULFATE AND SODIUM NI- TRATE.*

By R. S. POTTER AND R. S. SNYDER.

The importance of the organic matter in soils is universally recognized, but the rapidity with which this decomposes and is lost is hardly appreciated. It was recently pointed out by Swanson¹⁰ that 150 tons of vegetation were necessary to produce the organic matter in the surface of some typical Kansas soils. He also estimated that the least amount of organic matter which must be returned to these soils each year in addition to the stubble and corn stalks, in order to maintain their present content of organic matter, was one ton.

Therefore, studies on the rate of decomposition of the organic matter are of interest. This among other things is the object of investigations being carried on by us, and the following paper is the first of a series of reports on experiments with soil treated with various organic and inorganic fertilizers. In general the same points have been investigated, namely: loss of nitrogen as ammonia, evolution of carbon dioxide, and changes in the ammonia, nitrate, nitrogen and carbonate content. This report will be confined to the treatments indicated in the sub-title. The experimental work in connection with the work on stable and green manure is well under way, and will be reported when completed.

Before the details of the experiment are taken up, the investigations of others, pertinent to this work, will be discussed briefly.

HISTORICAL.

Loss of Nitrogen.

There are on record but few reports of carefully controlled pot experiments showing the effect of lime on the loss or gain of nitrogen. Numerous field experiments have been carried out, and while in general, for practical purposes, field experiments give the more valuable data, yet it is more difficult to control the various factors and hence any effect noted is not certainly due to any one variable.

In 1889 Schloesing¹⁷ introduced into flasks, eight different soils which had previously been growing legumes. The atmosphere was renewed weekly, and at the end of eleven months almost all of the soils showed a slight loss of nitrogen. In no case was there a gain of more than 0.01 gm. nitrogen per kilogram of soil.

In 1891 Berthelot³ found that clay soils when kept moist gradually lost nitrogen. He gives very few details in connection with his work.

*From the Laboratory of Soil Chemistry of the Iowa State Experiment Station.

The most important results in connection with the loss of nitrogen due to the liming of the soil were obtained by Lemmermann¹⁰ and his collaborators. The general plan of their experiments was as follows: Lime was added to the soils at the rate of 0.6 per cent, 1.0 per cent and 1.2 per cent. This corresponds to 6, 10 and 12 tons per acre.* Ammonium sulfate at the rate of 10 and 20 mg. per 100 gm. soil was used. Their general results and conclusions were as follows:

There was a very slight loss of nitrogen when soils were treated with lime, the greater losses being with the higher amounts. With the heavier treatment of ammonium sulfate and lime there was a considerable loss of nitrogen, while with the smaller treatments, a very slight loss occurred. For practical purposes, then, the results of these investigations show that soils containing, or treated with large amounts of calcium carbonate, will lose part of their nitrogen; but, as the authors point out, such treatments as they have used will but seldom be used in practice. The method by which a loss of nitrogen was detected was simply the determination of the total nitrogen of the soil before and after incubation. Because of the slight differences necessarily dealt with, extremely accurate work was necessary. The above investigators used in all cases the average of eight nitrogen determinations. It is shown in the experimental part of this paper that soil treated with three tons of lime and one-half ton of ammonium sulfate per acre lost an appreciable quantity of ammonia nitrogen, yet not enough to be detected by total nitrogen determinations.

Volatilization of Ammonia from the Soil.

Berthelot¹ placed moist soil in pots under bell jars in such a manner that the water which condensed on the bell jar ran into receiving vessels. The liquid thus collected was analyzed for ammonia by distillation with magnesia, and the residue was analyzed for total nitrogen. Plants were grown in some of the pots. The soil alone, gave off a very small amount of ammonia and other nitrogen compounds. Still less nitrogen in the form of ammonia and other compounds was collected from the jars with the plants.

Takeuchi²⁰ carried out an interesting and significant experiment relative to the loss of ammonia when ammonium sulfate is in contact with lime. Pure ammonium sulfate and lime were mixed with varying amounts of water. A current of air was passed through the mixture and then into standard acid. At room temperature but a trace of ammonia was given off.

Hall and Miller⁶ found that soils absorb a very small amount of ammonia from the atmosphere. Also more ammonia was collected in vessels containing acid when placed over fields recently manured with am-

*Throughout this report, by acre is meant 2,000,000 pounds of soil.

monium sulfate and chloride than when placed over untreated plots. They state that in all their tests it was found impossible to keep the dust from accumulating in the acid vessels, so it appears possible that the increase of ammonia might have been due to the higher content of ammonia in the dust from the ammonia treated plots.

Ehrenberg⁴ found that when large quantities of ammonium sulfate and calcium oxide were applied to soils, there was a considerable volatilization of ammonia, which seemed to be influenced by the wind. It was found in the same year that lime might even increase the power of the soil to absorb ammonia.¹¹ In the following year it was found in other experiments¹² that lime increased the rate of evaporation of ammonia from some soils, and decreased it with others. The procedure by which these results were obtained was to mix the soil with the lime and then pass air through the mixture.

It is thus seen that the data in regard to the action of lime relative to the evaporation of ammonia from the soil are very conflicting. None of the work thus far done has shown absolutely whether or not ammonia, as such, volatilizes from the soil alone and under the application of normal amounts of lime.

Ammonia and Nitrate Transformation.

The voluminous literature in connection with this phase of the subject will not be gone into here as this investigation was not planned primarily to add anything new to the existing data on the subject. Such data as were taken have been mainly to correlate with the other results.

Evolution of Carbon Dioxide.

The importance of carbon dioxide in agriculture and its value as a plant food solvent, direct fertilizer, etc., has long been recognized. Many laboratory and field tests of the amount of carbon dioxide produced by the soil and present in the soil atmosphere have been made. Only those which have a direct bearing on the work in hand will be discussed. Formerly the origin of the gas in the soil was thought to be the simple chemical decomposition of the organic matter in the soil, but Wollny²² has shown by experiments with sterilized soil, that practically all is due directly to the action of micro-organisms and the roots of higher plants.

Stoklasa¹⁸ who did some of the first fundamental work on carbon dioxide production in soil, calculated that certain bacteria produce from two to two and one-half grams carbon dioxide per 100 gm. dry bacteria in one hour. Van Suchtelen²¹ who gives an excellent and complete review of the work on carbon dioxide of the soil, measured the amount of the gas given off by various soils under different conditions and compared his results to the numbers of bacteria in the soil. A close relationship was found. His method was as follows: One kilogram of sand was

placed in an eight-litre flask and then 6 kg. of the soil on top of the sand. The carbon dioxide produced was measured by drawing air through the soil by means of a glass tube which reached through the soil down into the layer of sand. He found that the amount of carbon dioxide given varied somewhat with the amount of air passed through the soil, but there was less variation for the larger amounts than for the smaller amounts of air. It was found that much smaller amounts of carbon dioxide were given by soils completely saturated with water than soils somewhat below the saturation point. One-tenth of a gram of ammonium sulfate in 100 gm. soil caused a 500 per cent increase in the carbon dioxide produced. Many other interesting and significant experiments were carried out, and such as are pertinent to our work (to be reported on later) will be discussed at the proper time.

In 1911 Lemmermann * and associates published the report of an extensive investigation on the action of calcium oxide and carbonate on the production of carbon dioxide in soils. The plan of their first set of experiments was as follows: One kilogram of the dry soil, after the admixture of the materials to be added, was placed in a flask of about twice the volume of the soil. After making up to 12 per cent moisture, 10 liters of air were passed through the soil for a short time daily and the carbon dioxide collected and weighed. In this set, various organic fertilizers were used in combination with the lime. Curiously, there were no soils untreated with the manures. Since this experiment has more to do with our later work it will only be stated here that in general the limed pots gave off more carbon dioxide than the unlimed after deducting for that bound by the calcium oxide. It was assumed in the case of the soils treated with the carbonate that none of the evolved carbon dioxide came from this carbonate directly. This certainly would not be the case if the soil were at all acid, and it is doubtful if this would be true in any case. Certainly it is a point which should be investigated. In the next series of experiments by these investigators, much the same treatments were given except that calcium oxide alone was used. Instead of measuring the evolved carbon dioxide, the soils were analyzed before and after treatment for carbon by the combustion method. Where no lime or manure was added to the soil, in one case there was a loss of carbon and in the other, a gain. The lime caused a greater loss in both the unmanured and the manured soils than in the corresponding unlimed soils. In the next series calcium carbonate was used. Here again a greater loss of carbon from the limed soil was observed, and also no account was taken of the carbon from the carbonate. In these carbon balance experiments 0.1 per cent and 1 per cent lime were used.

Quite recently there has appeared a report from the Wisconsin Station * on the effect of various inorganic fertilizers upon the carbon diox-

ide production in a soil. The only fertilizer used in this instance, which has a direct connection with this work, was ammonium sulfate. One kilogram of soil after being mixed with the salt was placed in a two-liter Erlenmeyer suction flask and after being made up to about 18 per cent moisture the soils were incubated at room temperature for twelve days. Air was drawn through the apparatus for ten minutes every twenty-four hours during this period and the carbon dioxide collected and determined. Amounts of ammonium sulfate from 0.1 gm. to 1 gm. per 100 gm. soil were used. All of the treatments increased the carbon dioxide evolution. The increases were as follows: 0.1 gm. 55 per cent; 0.25 gm. 75 per cent; 0.5 gm. 55 per cent; 1.0 gm. 30 per cent Miami silt loam was the soil used. Nothing else is stated concerning its properties.

EXPERIMENTAL.

Several hundred pounds of Miami Silt loam were obtained from one of the station orchards, which is situated on the Wisconsin drift area. The soil is light in color, and low in organic matter. It contains 0.1137 per cent nitrogen and 1.35 per cent carbon. It has a lime requirement according to the Veitch method of 600 pounds of calcium carbonate per acre. After partially air drying, the soil was thoroughly mixed and then allowed to air dry completely. All but 80 to 90 pounds was placed in a tin storage can and reserved for the remaining experiments in this series. The smaller sample was spread out, thoroughly mixed again and exactly 1134 gm. ($2\frac{1}{2}$ pounds) was weighed out into glass pots whose height was 11.5 cm. and whose diameter was 11.5 cm. At the same time a small sample of the soil was drawn and sealed up in a Mason jar.

The general arrangement of the apparatus is shown in Figure 1 and the detailed arrangement in Plate I. The current of air, drawn by a water pump, first enters the flask A containing concentrated sulfuric acid, which takes the water and ammonia from the air. The object of removing the water is to keep the soda lime tube from clogging. The air then passes through tube B and C. Tube B holds 200 gm. of soda lime and tube C 1.5 kg. The soda lime in B is renewed every two or three days during the course of an experiment. The current of air is then divided, one-half going through D containing sulfuric acid of such a strength that it gives a partial pressure of water vapor about equal to the partial pressure of water vapor in the atmosphere of Iowa during the summer months. The other half of the air current goes through apparatus in all respects like that traversed by the half entering D. The current of air, after leaving D, goes through twelve tubes, each leading to a bell jar. Only one of these is shown in Fig. 2, but they are all arranged in exactly the same manner. The air, entering the bell jar E, which is 35 cm. in height and 15 cm. in diameter, passes over the soil in the pot F, bubbles through standard acid in G, and through 5 per cent potassium hydroxide in

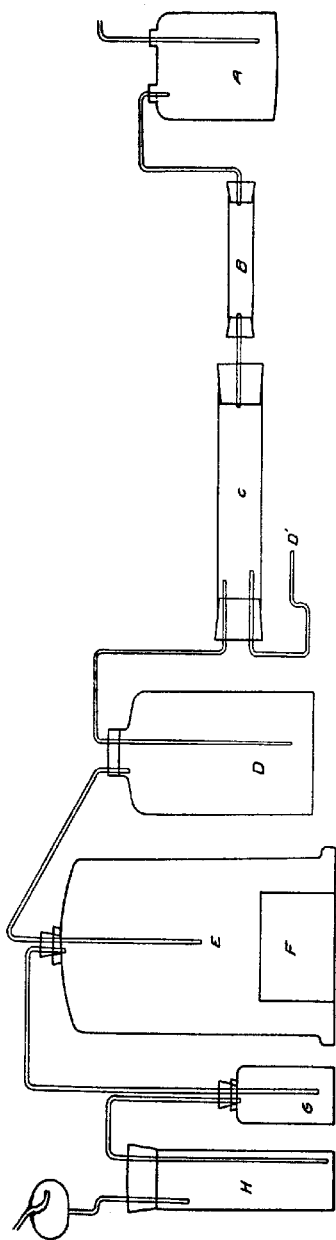


Figure 1.—Diagram of Apparatus Used in Determining Carbon and Nitrogen Changes in Soil Variously Treated.

H. H consists of a glass cylinder 20 cm. by 3.5 cm. The rubber stopper closing it bears a 25 cc. Kjeldahl connecting bulb. It is placed at such a height that when the air is passing through it, it is filled with alkali up to within a few mm. of the end of the bent exit tube. This makes a simple and effective carbon dioxide absorption tower. To test its efficiency two of these towers were connected in series to a bottle containing a dilute solution of sodium bicarbonate. A current of air was drawn through the system at about the rate used in all our work and very dilute acid was slowly dropped into the sodium bicarbonate solution. After one day the carbon dioxide was determined in the alkali in each bottle. After deducting the blank for the alkali, the tower next the bicarbonate solution contained 350 mg. carbon dioxide, while the next tower contained 0.9 mg. This was considered a sufficiently complete absorption for our purposes. The treatment of the pots of soils in tons (T) and pounds per acre was as follows:

POT NO.	TREATMENT.
1, 2, 13, 14	Check.
3, 4, 15, 16	3 T. CaCO_3
5, 6, 17, 18	1285 lbs. NaNO_3
7, 8, 19, 20	1000 lbs. $(\text{NH}_4)_2\text{SO}_4$
9, 10, 21, 22	3 T. CaCO_3 ; 1285 lbs. NaNO_3
11, 12, 23, 24	3 T. CaCO_3 ; 1000 lbs. $(\text{NH}_4)_2\text{SO}_4$

Just before starting the experiment air was drawn through the apparatus for an hour to free it of carbon dioxide. While this was being done 3.4 gm. lime (precipitated calcium carbonate) were added to the designated soils and very thoroughly mixed. The soil, whose saturation capacity for water was 34 per cent, was made up to 22 per cent moisture as follows: First a fresh soil emulsion was prepared by mixing 400 gm. of fresh field soil with four liters of ammonia and carbon dioxide free water. After allowing the soil to settle a few minutes three liters were decanted and then 100 c.c. were pipetted into each of twenty-four 250 c.c. flasks, numbered 1 to 24 to correspond to the pot numbers. Solutions of ammonium sulfate and sodium nitrate of such a strength that 100 c.c. contained the required amount (0.5670 gm. and 0.7393 gm. respectively) were prepared. Quantities of 100 c.c. of each of these solutions were pipetted into the proper flasks and then all the flasks were made up to the mark with ammonia and carbon dioxide free water. After being shaken, the mixtures were poured into their respective soils, which were then immediately transferred* to the proper bell jars. The current of air was

*In all the later work the procedure at this point was somewhat different. All the dry ingredients were mixed with the soils and the pots containing the soils were placed under the bell jars. Carbon dioxide free air was then passed through the apparatus for an hour or more. Then the 250 c.c. of water (emulsion, etc.) was added to the soil by means of a long funnel. By the original method of procedure, no doubt, there was a slight loss of carbon dioxide, but by comparison with work done by the second method of procedure it was found that this loss was relatively negligible.

turned on and run continuously throughout the period of the experiment. The experiment was started October 31, 1914. The alkali was transferred and the carbon dioxide estimated on the days shown in Table I. Pots Nos. 1 to 12 were run until November 27 and Nos. 13 to 24 until January 18. Only the carbon dioxide results for the pots which were run the longer period are reported. Only two titrations were run on the other set and these agreed very closely with those given.

Besides the determination of the evolved carbon dioxide, the ammonia liberated was determined. The original intention was to estimate the ammonia and carbon dioxide at the same time, but the amount of the former given off was so small this plan was abandoned. In this experiment 0.02 N acid was used as the absorbent. For the soils Nos. 1 to 12 this was titrated directly with 0.02 alkali. Afterwards it was thought that part of the "ammonia" thus found was due to alkali dissolved from the bottle. Therefore for the remaining soils, at the completion of the "run" the acid was transferred to Kjeldahl flasks, made alkaline and the ammonia aerated into standard acid. The results apparently confirmed the suspicion that part of the alkalinity was due to the bottles.

METHODS OF ANALYSIS.

Total Nitrogen.

Twenty-five gm. of soil were used for each determination. The salicylic acid method was used, the reduction being carried out by powdered zinc and the digestion after the Kjeldahl-Gunning method. Instead of distillation of the ammonia it was determined by the aeration method of Kober and Graves.⁸ Probably because of the insoluble residue in soil digestions we have found it necessary to aerate these solutions longer than the originators of the method advised. Using a current of air of about 500 liters an hour for two and one-half hours was found to recover all of the ammonia, but for certainty all our aerations were run for three and one-half hours or more. Only by extreme care in every operation was the probable error of the determinations reduced as low as it was. By this method, working with this and other soils, we were able to determine all of 150 parts per million of nitrate nitrogen added to the soil. All determinations were made in quadruplicate.

Ammonia Nitrogen.

This was determined by the method proposed by the authors.¹⁴ It was thought that in the case of limed soils there would be a loss of ammonia upon air drying. Some of the limed samples containing the larger amount of ammonia were analyzed in the moist condition and also after quickly air drying by the aid of an electric fan. In all cases the same amount of ammonia was found before and after the drying. All determinations were made in duplicate.

Nitrate Nitrogen.

Nitrates were determined by the modification of the aluminum reduction method as proposed by Burgess³ using the apparatus proposed by us.¹⁵ The determinations were always made on the wet soil within two hours after removing from the pots.

Carbonates.

The determination was made by the method of MacIntire and Willis,¹⁸ using a somewhat different apparatus than that used by them. A Kjeldahl flask contained the soil and the absorption tower was just like the one used in the main part of the experiment. According to our experience the atmospheric blank was not sufficiently constant to be included in the alkali blank. In all cases the apparatus was carefully freed from carbon dioxide. One part of 85 per cent phosphoric acid to fifteen parts of water was used. This was shown by the sponsors of the method to decompose quantitatively calcium carbonate in the soil.

In Table I are found the results of the carbon dioxide determinations, expressed in pounds per acre.

It will be observed that there are no results given for the time between December 11 and 19. During that time the apparatus sprung a leak at such a place that it was not apparent to us, and all the results were high for that period. The degree of closeness with which the duplicate soils agreed is considered satisfactory. Something more in this connection should be said in regard to the method of drawing out the carbon dioxide from the soil. It will be observed from the historical section of this paper that all of the previous work involved drawing the air either over or through the soil during only a short period once a day. In our work we attempted to have the air current the same over each pot, but this was adjusted only by observing the rate of bubbling of the air. This, at best, would give currents of air only approximately the same. The amount of air going over in twenty-four hours was from 25 to 50 liters. It was in these and later experiments observed that if one of the streams of air became partially or completely stopped for perhaps a day and then turned on fast for several hours before estimating the carbon dioxide the amount of the gas given off by this pot would be lower than its duplicate, and the deficit would never be made up. On the other hand, if one of the streams of air was turned on 5 or 10 times as fast as its duplicate, if the latter ran normally the duplicates would check as closely as ordinarily. It was recently¹⁹ found that the content of carbon dioxide in the soil atmosphere was not appreciably changed by high and continuous winds. In view of these facts it appears that experiments involving the drawing out of the carbon dioxide only once or even twice would not give correct results. There would undoubtedly be a lessened production

TABLE I.
CARBON DIOXIDE DETERMINATIONS.
(Expressed in terms of pound per acre.)

Pot. No.	Treatment	Oct. 31-Nov. 2	Nov. 2-6	Nov. 6-13	Nov. 13-20	Nov. 20-27	Nov. 27-Dec. 4	Dec. 4-11	Average	Dec. 11-19	Dec. 19-31	Average	Dec. 31-Jan. 8	Jan. 8-18	Average	Total	Average
13	Check.....	287	220	258	148	143	130	113	111	(138)c	201	203	(153)a	190	187	1960	1970
14	Check.....	274	226	249	151	145	126	109	111	(138)c	205	203	(153)a	184	187	1960	1970
15	Lime.....	1205	1186	1186	1186	1186	1186	1186	1186	(138)c	205	203	(153)a	184	187	1960	1970
16	Lime.....	1205	1186	1186	1186	1186	1186	1186	1186	(138)c	205	203	(153)a	184	187	1960	1970
17	NaNO ₃	282	277	277	277	277	277	277	277	(138)c	205	203	(153)a	184	187	1960	1970
18	NaNO ₃	282	277	277	277	277	277	277	277	(138)c	205	203	(153)a	184	187	1960	1970
19	(NH ₄) ₂ SO ₄	308	290	290	290	290	290	290	290	(138)c	205	203	(153)a	184	187	1960	1970
20	(NH ₄) ₂ SO ₄	308	290	290	290	290	290	290	290	(138)c	205	203	(153)a	184	187	1960	1970
21	Lime & NaNO ₃	1109	1109	1109	1109	1109	1109	1109	1109	(138)c	205	203	(153)a	184	187	1960	1970
22	Lime & NaNO ₃	1165	1137	1137	1137	1137	1137	1137	1137	(138)c	205	203	(153)a	184	187	1960	1970
23	Lime & (NH ₄) ₂ SO ₄	1083	1083	1083	1083	1083	1083	1083	1083	(138)c	205	203	(153)a	184	187	1960	1970
24	Lime & (NH ₄) ₂ SO ₄	1079	1061	1061	1061	1061	1061	1061	1061	(138)c	205	203	(153)a	184	187	1960	1970

(a) Value assumed to be the same as duplicate.

(b) Value taken arbitrarily from general direction of curves.

(c) Value taken directly from the curves.

of the gas under these conditions. It is not certain just why this should be so but the increase in the partial pressure of the carbon dioxide acting according to the mass action law would slow up the production and then the excess carbon dioxide would tend to be toxic to the bacteria. The current of air in our experiments assuming thorough mixing in the bell jar maintained an air mixture having a partial pressure of carbon dioxide somewhat below that in the normal atmosphere.

The results for the various periods have been divided by the number of days in the period. This gives the average amount of gas given off per day for the respective period. The results found in Table II have been plotted and are shown in Figure 2. The curves as plotted carry the assumption that the average amount of carbon dioxide given off per day each period was being given off at that rate in the exact middle of the period. While not absolutely justifiable, some such an assumption seems necessary. The points of the curve between December 11 and December 19, which were lost have been assumed to lie on a straight line between the two points before and after this time. This is the best that can be done and is no doubt not far from correct because the general tendency of all the curves is to be in straight lines.

TABLE II.
AVERAGE AMOUNT OF CARBON DIOXIDE GIVEN OFF PER DAY IN SOIL
VARIOUSLY TREATED.

Treatment	Pot. No.	Oct. 31-Nov. 2	Nov. 2-6	Nov. 6-13	Nov. 13-20	Nov. 20-27	Nov. 27-Dec. 4	Dec. 4-11	Dec. 19-31	Dec. 31-Jan. 8	Jan. 8-18
Check	13, 14	140	55.5	36.1	21.3	20.6	18.3	15.9	18.5	19.1	18.7
3 T. CaCO_3	15, 16	593	109.7	69.7	36.6	32.6	32.7	25.0	32.7	30.9	29.5
1285 lbs. NaNO_3	17, 18	138.5	43.7	30.2	18.4	18.1	16.3	13.4	13.5	15.0	14.9
1000 lbs. $(\text{NH}_4)_2\text{SO}_4$	19, 20	245	40.5	31.1	18.6	18.0	15.7	14.7	15.5	16.0	15.7
3 T. CaCO_3 + 1285 lbs. NaNO_3	21, 22	568.5	88.2	69.1	35.7	37.6	29.3	27.9	25.5	26.6	26.4
3 T. CaCO_3 + 1000 lbs. $(\text{NH}_4)_2\text{SO}_4$	23, 24	540.5	87.5	lost	lost	30.6	22.0	20.0	22.1	21.6	20.1

The most striking thing shown by the curves is the rapidity with which they drop to nearly horizontal lines. This is not surprising for the limed soils but the reason is not so apparent for the unlimed. That it is not due to the freeing of carbon dioxide mechanically held in the soil is shown by the analysis of the soil for carbonates. By the analysis of the original soil 318 pounds per acre of carbon dioxide were found. In the case of the check pots if it is assumed that the normal carbon dioxide production is 20 pounds a day after November 13, then the excess during the first thirteen days was 495 pounds. Therefore if all of the carbon dioxide found by the analysis of the soil were mechanically held and all of it were given off in the first few days, neither of which assumptions is

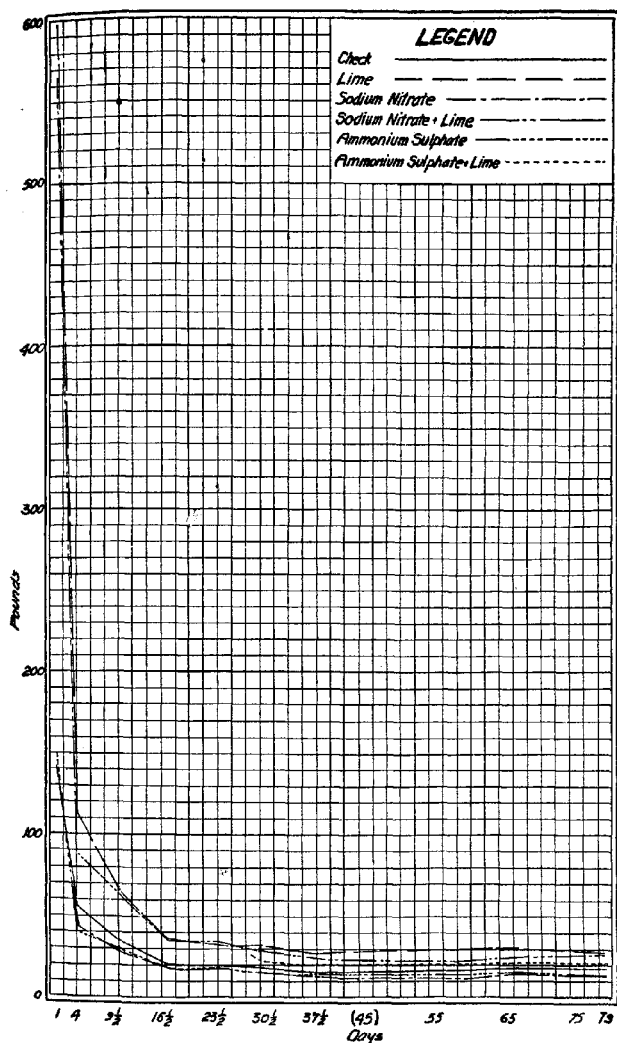


Figure 2—Diagram Showing the Average Amount of Carbon Dioxide given off per Day in Soil Variously Treated.

probable, there would still be an excess of 177 pounds given off during the first thirteen days.

It has been shown by Klein ⁷ that the carbon dioxide production of soils is enhanced by previous drying and that the water soluble matter is increased in a clay loam soil low in organic matter. Perhaps the increase in the water soluble material, making a richer nutrient solution, is the cause of the increased carbon dioxide production. After a few days this rich nutrient solution would reach its normal concentration for the particular soil and the bacterial activities would be somewhat lessened. It was recently shown by Russell and Appleyard¹⁶ that an increase in the carbon dioxide in the soil atmosphere of field soils after rains was always accompanied by a decrease in nitrates. They, therefore, concluded that the oxygen of the nitrates was utilized in the oxidation processes. In the soil used there were 44.3 pounds of nitrate nitrogen or 217 pounds of sodium nitrate. This might have served to enhance the carbon dioxide production. Still another factor which might have contributed to the initially large amount of carbon dioxide evolved is the fact that previous drying of the soil alters the colloidal condition of the soil, permitting an enhanced rate of oxidation.⁷

The data in regard to the carbonate content of the soils are given in Table III. The values which are given are the average of two closely agreeing duplicates. The results are expressed in pounds per acre of carbon dioxide and calcium carbonate.

TABLE III.
CARBONATE CONTENT OF SOILS.

Soil	CO ₂ in lbs. per A.	Average	CaCO ₃ in lbs. per A.	Average	Soil	CO ₂ in lbs. per A.	Average	CaCO ₃ in lbs. per A.	Average
Original	198	.....	676	.....	13	115	.....	261	.....
1	170	.....	386	.....	14	115	115	261	261
2	170	170	386	386	15	lost	.....	.....	.....
3	548	.....	1245	.....	16	492	.....	1118	1118
4	540	544	1225	1235	17	49	.....	1112	.....
5	40	.....	90.8	.....	18	58	53.5	1430	1276
6	36	38	81.6	86.2	19	53	.....	1316	.....
7	36	.....	81.6	.....	20	58	55.5	1430	1373
8	40	38	90.8	86.2	21	492	.....	1118	.....
9	448	.....	1016	.....	22	496	494	1126	1124
10	545	496.5	1238	1127	23	386	.....	876	.....
11	282	.....	640	.....	24	381	383.5	865	870.5
12	339	310.5	770	705					

The carbon dioxide which is the direct result of the decomposition of organic matter was also computed. Where A is the carbon dioxide evolved, B that originally present in the soil, including that added in the lime, and C that left in the soil, and X is that which is the direct result of organic decomposition, then

$$A-(B-C)=X.$$

The data so obtained are given in Table IV.

TABLE IV.
COMPOSITION OF CARBON DIOXIDE EVOLVED FROM ORGANIC
DECOMPOSITIONS.

Treatment	Soil	CO ₂ added in CaCO ₃ lbs. per Acre	CO ₂ from Organic Matter lbs. per Acre
Check	13, 14	.....	1787
3 T. CaCO ₃	15, 16	2,637	1693
1285 lbs. NaNO ₃	17, 18	.....	1411.5
1000 lbs. (NH ₄) ₂ SO ₄	19, 20	.....	1472.5
3 T. CaCO ₃ + 1285 lbs. NaNO ₃	21, 22	2,637	1387
3 T. CaCO ₃ + 1000 lbs. (NH ₄) ₂ SO ₄	23, 24	2,637	893.5

The results as given in Table IV are, to say the least, astonishing. Lime has time and again been proven to increase the bacterial activity of soils, yet in this case there is less decomposition in the case of the limed pots than in the unlimed. Perhaps if the experiment had been run for a longer time the results would have been different. This would be true if the curves for the carbon dioxide production had continued in a horizontal direction as the last few points indicated would be the case. In fact, in another experiment to be reported on later it was found in the case of four pots made up with the same soil and exactly like pots Nos. 1 to 4 in this series, except that they were run 18 weeks, that the limed soils did give off more carbon dioxide from the organic material than did the unlimed. Just why the increase does not manifest itself immediately is not certain. It is possible that the large amount of the gas given off by the limed pots inhibits the action of the bacteria until it has diffused from the soil. It is believed that the experimental error involved in the determination of the evolved carbon dioxide is quite small, but the error in the determination of the residual carbon dioxide in the soil is relatively large. An error in the titration of 0.1 c.c. for instance, makes an error of 17.7 pounds of carbon dioxide per acre. But the greatest variation of any of the duplicate titrations of the carbon dioxide in these soils was just 0.1 c.c., so it seems that the variations in the above table are well outside the experimental error. However, the values for the pots 23 and 24 involving so many assumed values might quite possibly be too low. Our results for ammonium sulfate are certainly contrary to those of Van Suchtelen²¹ and Fred and Hart.⁵ The soil used by the two later investigators was a Miami Silt Loam, the same type as ours, yet there might have been decided differences in organic matter content, reaction, etc. The great differences are, no doubt due to the differences in the soil flora. It is also observed that the sodium nitrate treated pots show a decreased carbon dioxide production. The reason for this is not clear. The only

apparent explanation is that sodium nitrate at this concentration is toxic. This however is hardly probable.

In Table V the ammonia evolved by the soils will be considered. The results are expressed in pounds of nitrogen per acre. Except for pots 23 and 24 all the duplicate soils checked quite closely, hence for them only the averages are given.

TABLE V.
AMMONIA EVOLVED FROM SOILS.

Treatment	Soil	Ammonia Nitrogen lbs. per Acre	Soil	Ammonia Nitrogen lbs. per Acre
Check	1, 2	0.5	13, 14	0.35
3 T. CaCO_3	3, 4	0.55	15, 16	0.25
1285 lbs. NaNO_3	5, 6	0.5	17, 18	0.30
1000 lbs. $(\text{NH}_4)_2\text{SO}_4$	7, 8	0.85	19, 20	0.30
3 T. CaCO_3 + 1285 lbs. NaNO_3	9, 10	0.85	21, 22	0.35
3 T. CaCO_3 + 1000 lbs. $(\text{NH}_4)_2\text{SO}_4$	11, 12	1.5	23	2.4
			24	2.95

The losses while small were definite. For instance, one c.c. of 0.02 N. ammonia is equivalent to 0.5 pound of nitrogen per acre. As pointed out in the introduction, no doubt Nos. 1 to 12 are too high. The small amount of ammonia nitrogen lost from the limed pots is interesting. The loss of 2.7 pounds from pots 23 and 24 in the 12 weeks, if kept up would mean a loss of about 11 pounds during the year. However, as shown by Table VI the ammonium sulfate is gradually becoming transformed, so that the loss after the 12 weeks would be no greater than the soils receiving no ammonium sulfate.

In Table VI the amounts of ammoniacal and nitrate nitrogen are given. They are expressed in pounds of nitrogen per acre.

It will be recalled that 212 pounds of nitrogen was added to pots 5 to 12 and 17 to 24. The above data are of interest because, to the knowledge of the authors, they are obtained from the only experiment of its kind, showing the transformation of ammonium sulfate and sodium nitrate using an absolute method for ammonia. In all other like experiments the magnesia method or the hydrochloric acid extraction method have been used. The former gives too high results and the latter too low.

The results from the above table suggest a possible reason for the depression of the carbon dioxide production in the ammonium sulfate treated pots. In the case of these soils it seems that in no instance has it all been nitrified, which shows that at least ammonification has not been increased by the presence of the nitrate. Therefore it is possible that there has been such an increase in the nitrification that the number of the bacteria has been reduced and hence carbon dioxide production inhibited. It is a well known fact that the nitrifiers can live and multiply in a medium free from organic matter. If, as our results show, there is a depression

in the carbon dioxide production, due to the application of ammonium sulfate, this need cause no deleterious result for the nitrifiers are apparently considerably activated. The finding of less nitrate nitrogen in the sodium nitrate treated pots than actually had been added is not, of course, necessarily due to denitrification in the narrow sense of the term; it is more probably due to assimilation.

TABLE VI.
NITROGEN IN THE SOILS AS AMMONIA AND NITRATE.

Treatment	Soil	Ammonia as lbs. Nitrogen per A.	Nitrate as lbs. Nitrogen per A.	Average	Excess over the corres- ponding Unfertilized Pots
	Original				
Check	1	12.6	44.3	.....	.....
(ditto)	2	11.4	60.7	.....	.....
3 T. CaCO ₃	3	18.8	60.7	60.7	.....
(ditto)	4	14.8	68.8	.....	.....
1285 lbs. NaNO ₃	5	14.8	72.1	70.4	.....
(ditto)	6	11.4	219.8	.....	.....
1000 lbs. (NH ₄) ₂ SO ₄	7	12.4	218.1	218.9	158.2
(ditto)	8	13.6	104.8	.....	.....
3 T. CaCO ₃ + 1285 lbs. NaNO ₃	9	13.4	104.8	104.8	44.1
(ditto)	10	17.2	209.8	.....	.....
3 T. CaCO ₃ + 1000 lbs. (NH ₄) ₂ SO ₄	11	14.6	209.8	209.8	139.4
(ditto)	12	11.6	196.8	.....	.....
Check	13	16.4	196.8	196.8	126.4
(ditto)	14	13.4	82.4	.....	.....
3 T. CaCO ₃	15	13.2	83.4	82.9	.....
(ditto)	16	lost	lost	.....	.....
1285 lbs. NaNO ₃	17	13.0	113.4	113.4	.....
(ditto)	18	18.1	275.2	.....	.....
1000 lbs. (NH ₄) ₂ SO ₄	19	19.3	283.	279.1	196.2
(ditto)	20	34.6	257.6	.....	.....
3 T. CaCO ₃ + 1285 lbs. NaNO ₃	21	36.2	261.2	259.4	176.5
(ditto)	22	14.6	323.6	.....	.....
3 T. CaCO ₃ + 1000 lbs. (NH ₄) ₂ SO ₄	23	14.6	322.4	323.0	209.6
(ditto)	24	18.1	305.6	.....	.....
		18.6	306.8	306.2	192.8

As mentioned in the introduction, all total nitrogen determinations were carried out in quadruplicate. In the second column of Table VII the average and the probable error of these determinations are given. In the third column the average of the duplicate pots are given. In the next column are the corrected values. There is a slight correction to be applied to the limed soils. Assuming that after the experiment 2 gm. of lime remained, due to the "dilution" of the soil by this amount, 0.0002 has been added to each value. The amount of nitrogen added to the respective pots, 0.01060 per cent has been subtracted. While the gain or loss given in the last column, in most cases is small, yet it is thought dependence can be placed in the ones which are greater than 0.0010. The untreated soils in the case of the four weeks' run show a slight loss and no change for the twelve weeks. The limed pots in both cases show a slight gain. The unlimed sodium nitrate treated pots both show a loss, and the four and twelve weeks' results being so nearly alike indicate that the loss all came at first. The total nitrogen of the limed sodium nitrate

pots is unchanged, indicating that the lime has done away with the loss of nitrogen, which loss might or might not have been due to denitrification.

There are only slight changes in the ammonium sulfate-treated pots. The loss of ammonia from soils 23 and 24, computed to the same basis as this table was 0.00013. It is seen, therefore, that to check the loss of ammonia from soil by total nitrogen determination is impossible unless much larger losses are involved than was found in this work.

TABLE VII.
DETERMINATION OF NITROGEN CONTENT OF SOILS.

Treatment	Pot No.	Nitrogen in per cent. of Oven Dry Soil	Average	Average Corrected	Loss or Gain
Check	1	.11228 ± .00028			
(ditto)	2	.11277 ± .00032	.11253	.1125	— .0012
3 T. CaCO ₃	3	.11484 ± .00011			
(ditto)	4	.11488 ± .00019	.11482	.1150	+ .0013
1285 lbs. NaNO ₃	5	.12129 ± .00010			
(ditto)	6	.12176 ± .00013	.12153	.1109	— .0028
1000 lbs. (NH ₄) ₂ SO ₄	7	.12630 ± .00021			
(ditto)	8	.12632 ± .00022	.12631	.1157	+ .0020
3 T. CaCO ₃ + 1285 lbs. NaNO ₃	9	.12384 ± .00016			
(ditto)	10	.12375 ± .00005	.12479	.1144	+ .0007
3 T. CaCO ₃ + 1000 lbs. (NH ₄) ₂ SO ₄	11	.12370 ± .00039			
(ditto)	12	.12307 ± .00016	.12338	.1130	— .0007
Check	13	.11370 ± .00000			
(ditto)	14	.11379 ± .00021	.11374	.1137	.0000
3 T. CaCO ₃	15	lost			
(ditto)	16	.11428 ± .00016	.11428	.1145	+ .0008
1285 lbs. NaNO ₃	17	.12202 ± .00021			
(ditto)	18	.12150 ± .00059	.12176	.1112	— .0025
1000 lbs. (NH ₄) ₂ SO ₄	19	.12412 ± .00000			
(ditto)	20	.12598 ± .00010	.12505	.11445	+ .00075
3 T. CaCO ₃ + 1285 lbs. NaNO ₃	21	.12381 ± .00010			
(ditto)	22	.12465 ± .00018	.12423	.1138	+ .0001
3 T. CaCO ₃ + 1000 lbs. (NH ₄) ₂ SO ₄	23	.12368 ± .00010			
(ditto)	24	.12340 ± .00000	.12354	.1131	— .0006
Original		.11370 ± .00022		.1137	

SUMMARY AND CONCLUSIONS.

1. In conclusion it should be stated that we are at this time planning some rather exhaustive investigations into the relation of the amount of carbon dioxide given off by soils to the manner and speed of drawing the air over and through the soil. As stated earlier in this paper, it seems that some such method as we have used would give results more typical of field conditions than where the air was drawn *through* the soil. Possibly the rate at which the air is drawn over the soil is of considerable importance. These and other points are being investigated. Until these points are settled too great emphasis will not be placed on the relative amounts of carbon dioxide evolved in this experiment.

2. For all the soils except those treated with both ammonium sulfate and lime, about 0.3 pound of ammonia nitrogen was given off in the

twelve weeks. If kept up throughout the year this would mean a loss of a little over a pound per acre in a year, an insignificant amount when compared to that lost by leaching, cropping, etc. The loss from the soils treated with both lime and ammonium sulfate was about ten times as high for the period of the experiment, but it is not at all probable that this rate would be held for a very long period after the application of the sulfate. Therefore, we can say with considerable assurance that the danger of loss of ammonical nitrogen from the soil of the type used here is practically negligible.

3. In a general way, the total nitrogen determinations show there is a smaller loss or a greater gain of nitrogen for the limed soils than the corresponding unlimed soils. Whether the losses are due to denitrification or not, it cannot be said. The loss of nitrogen from the sodium nitrate treated soils and the gain of nitrogen in those soils treated with both sodium nitrate and lime, points to denitrification, yet this seems improbable, for the soil in question is a soil low in organic matter, in good physical condition and not water logged. But in whatever manner the nitrogen was lost there are points which must be investigated before results obtained as have these can be applied to field conditions.

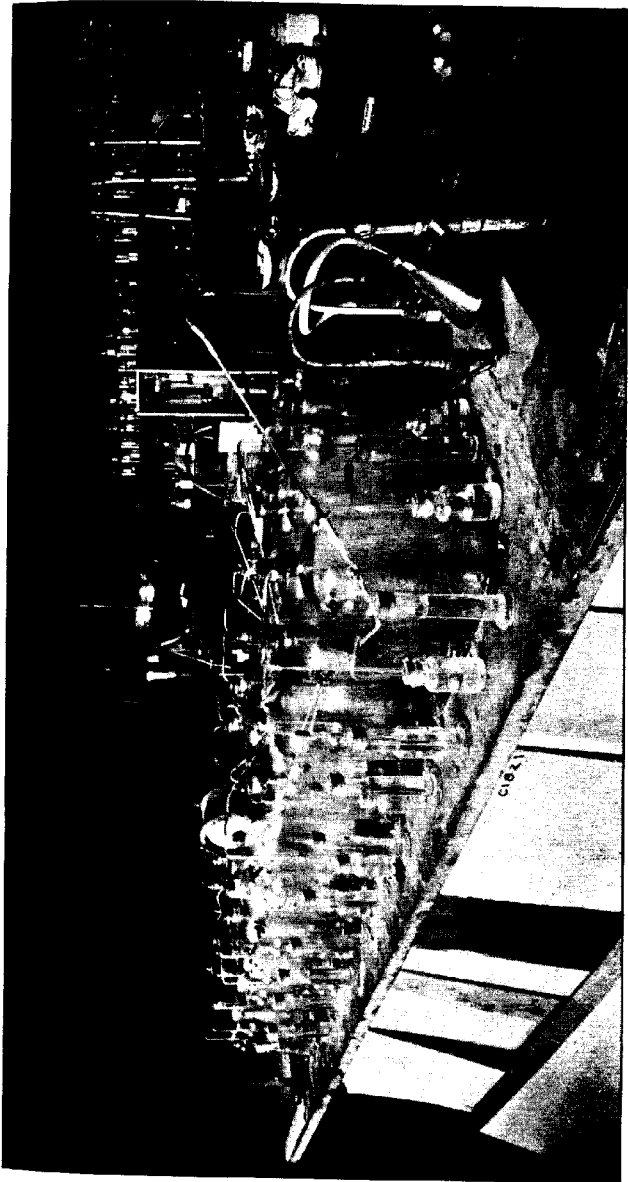
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PLATE I

**Apparatus Used in Determining Carbon and Nitrogen Changes in Soil Variously
Treated.**



EFFECT OF GRINDING ON THE LIME REQUIREMENT OF SOILS.*

By R. C. COOK.

In applying the Veitch method for the determination of soil acidity, a question often arises as to the fineness of the soil sample. Obviously, the use of a fine sieve will make necessary the elimination of a large part of the soil and hence give misleading results when calculated to the acre basis. On the other hand, the use of a sieve with meshes too large may be equally objectionable. If, therefore, the soil might be ground so that a representative sample could be obtained, the problem of getting more dependable results would be greatly simplified.

But in the grinding process a modification of the soil reaction undoubtedly takes place. The effect of this treatment on some Iowa soils has been recently recorded by Brown and Johnson.¹ Certain sandy soils were ground and tested for acidity, with the result that in all cases noted the lime requirement was reduced by grinding. In fact, some soils having a high lime requirement before treatment became basic thereafter. It is interesting to note that the finer the soil was ground the more basic it became, and also that the increase in basicity was roughly proportional to the amount of sand contained.

An explanation of this behavior might possibly lie in the assumption that the portions of the soils designated as "sand" were not sand in the chemical sense, but consisted of particles having a basic internal constitution, the surface of which may have become acid from exposure, or other causes. In this case the grinding, therefore, would be expected to increase the basicity. Since the finer particles of the soils are ordinarily composed of the more easily altered minerals it would not seem advisable to change their constitution more than necessary. There would also be no reason for grinding the fine particles which were already of the required fineness. Consequently, only those portions remaining upon the sieve were used in the grinding. Whether this procedure was followed, or the whole sample ground, is not stated in the work done at the Iowa Station.

If the sandy portions were silica, it appears that grinding would expose a greater portion of the acidic material and accordingly increase the acidity. It seems to be an established fact, as well, that for the same

* From the Soil Chemistry Laboratory, Rutgers College.

¹ Brown, P. E., and Johnson, H. W., The effect of grinding the soil on its reaction as determined by the Veitch method. *In* Jour. Amer. Soc. Agron., v. 7, no. 5, pp. 216-220, 1915.

material, that part which is in the finer state of division will usually manifest greater absorptive power. This physical factor strengthens our reasons for believing that the grinding of quartz sand would raise its "apparent acidity."

To test this point a sample of sand was examined for acidity both before and after grinding. The results recorded below seem to agree fully with the statements just made.

	Pounds CaO required per 3,500,000 pounds sand.
Quartz sand, unground	247.5
Quartz sand, ground to pass 100-mesh sieve	412.5
Increase due to grinding	165.0

Now if grinding free sand should increase its acidity there seems to be no reason why sand in soils (which in most sandy soils of New Jersey consists largely of silica and undecomposed silicates acidic in character) should not behave in a similar manner. With this in mind, a sandy soil was secured, put through a three-millimeter sieve, and that portion remaining on a 40-mesh screen was employed in the next determination. Most of this material was distinctly quartz and feldspathic mineral substance. A part of this was ground to pass an 80-mesh sieve, and the acidity of the ground and unground soil was then determined.

	Pounds CaO required per 3,500,000 pounds soil.
Sandy soil, unground	1320
Sandy soil, ground to pass 80-mesh sieve	1815
Increase due to grinding	495

Since this experiment served to corroborate the observation made with the quartz sand it was decided to test a number of soils to see if some, at least, would not react as indicated above. Samples of six different soils were obtained and prepared for determinations of acidity by passing them through a three-millimeter sieve. The soils were then further sieved through an 80-mesh sieve *and only those portions remaining upon it were ground*. When all was reduced to this fineness the ground material and that previously sieved were thoroughly mixed and the lime requirements of this and of the unground soil were determined.

The grinding was accomplished as before in a porcelain mortar. Any of the porcelain which may have been ground off did not seem to appreciably affect the reaction as determined in a blank. However, the estimation of the blank could not be made absolutely true, inasmuch as more porcelain would be taken off when the soil was being ground than when the mortar and pestle were used alone. It is, therefore, not impossible that a slight error was introduced at this point.

The results of the determinations made in each case are averaged and tabulated below:

POUNDS CaO REQUIRED PER 3,500,000 POUNDS SOIL.

Type	Soil No.1 Sass. Sandy Loam	Soil No.2 Norfolk Sand	Soil No.3 Colling- ton Sandy Loam	Soil No.4 Soil No.5 Soil No.6		
				Sassafrass	Gravelly	Loam
Sieved through 3 mm.	3135	1320	1485	Neutral	2970	3052.5
Sieved through 3 mm. and ground to pass 80-mesh	3630	1650	1732.5	412.5	3630	3217.5
Increase due to grinding	495	330	247.5	412.5	660	165.0

Here again there is shown to be an increase in acidity in all cases due to grinding. In one instance, that of Soil No. 4, a neutral soil became acid by this treatment. The increases observed do not appear to be much larger than could be accounted for by the increased surface of the sand particles, assuming them to be made up largely of silica.

There is some variation in the amounts of increases and it seemed worth while to determine if an approximate mechanical analysis would be of any value in explaining these differences.

MECHANICAL ANALYSIS OF SOILS.

Mesh	Soil No.1	Soil No.2	Soil No.3	Soil No.4	Soil No.5	Soil No.6
	%	%	%	%	%	%
3 mm.-20 meshes per inch	12	0	6	15	17	10
20-40 meshes per inch...	30	2	17	22	30	28
40-80 meshes per inch...	30	46	32	43	30	37
80 and above.....	28	52	45	20	23	25

An examination of this table does not offer much enlightenment upon the behavior observed. However, if we eliminate Soil No. 6, we get a correlation between the amount of acidity increase and the proportion of soil remaining above an 80-mesh sieve. Soils Nos. 2 and 3 then, show the lowest increases and show also the least amount of sand to be ground. Conversely, the largest increases are noted for Soils Nos. 1, 4, and 5, where the percentages of coarse particles are large. No explanation is offered for the slight alteration to Soil No. 6.

That diametrically opposite results were obtained at the Iowa station may point to a very interesting difference in the respective soil types. In no case, however, was the increase in acidity in New Jersey soils nearly as marked as the increase in basicity in Iowa soils, but the grinding has a distinct effect in either instance. Both observations point to the fact that soils should not be ground for acidity determinations.

SUMMARY.

The experiments outlined above tend to indicate that:

1. Soils should not be ground if used for determination of lime requirement by the Veitch method;
2. Grinding sandy soils of New Jersey increases their acidity, instead of decreasing it, according to the method employed.

